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Environmental Protection Agency

Part II

Environmental Protection Agency

40 CFR Parts 141 and 142

National Primary Drinking Water
Regulations; Radionuclides; Proposed
Rule

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Parts 141, 142

[WH-FRL 3956-4]

RIN 2040-AA94

National Primary Drinking Water Regulations; Radionuclides

AGENCY: Environmental Protection Agency.

ACTION: Notice of proposed rulemaking.

SUMMARY: In this action under the Safe Drinking Water Act (as amended in 1986), the Environmental Protection Agency (EPA) is proposing Maximum Contaminant Level Goals (MCLGs) and National Primary Drinking Water Regulations for the following radionuclides: radon-222, radium-226, radium-228, uranium, alpha emitters, and beta particle and photon emitters. These radionuclides are classified as group A human carcinogens according to EPA's classification scheme; also, uranium is toxic to the kidneys. This notice proposes MCLGs, Maximum Contaminant Levels (MCLs), monitoring, reporting, and public notification requirements for these radionuclides.

DATES: Written comments should be submitted by October 16, 1991. A public hearing will be held on September 6, 1991 in Washington, DC beginning at 9 a.m. A second public meeting will be held on September 12, 1991 in Chicago, Illinois at 9 a.m. Washington hearing speakers should register by August 23. Chicago hearing speakers should register by August 30.

ADDRESSES: Send written comments to Comments Clerk—Radionuclides, Drinking Water Standards Division, Office of Ground Water and Drinking Water (WH-550D), Environmental Protection Agency, 401 M Street, SW., Washington, DC 20460. A copy of all public comments and supporting documents for this proposed regulation will be available for review at EPA, Ground Water and Drinking Water Docket, 401 M Street, SW., Washington, DC 20460. For access to the docket materials, call 202-382-3027 between 9 a.m. and 3:30 p.m. Commenters are requested to submit one original and three copies of their written comments. Commenters who wish to receive acknowledgement of receipt of their comments should include a self addressed stamped envelope. All comments must be post marked or delivered by hand by October 16, 1991. No facsimiles (faxes) will be accepted, as EPA is not equipped to receive the

large volume of comments expected to arrive near the close of the comment period, and cannot assure that faxes will be delivered to the docket. Major supporting documents cited in the reference section of the proposed rule will be available for inspection at the Drinking Water Supply Branches in EPA's Regional Offices listed below:

- I. JFK Federal Bldg., (One Congress Street, 11th floor), Boston, MA 02203, Phone: (617) 565-3610, Jerome Healey
 - II. 26 Federal Plaza, Room 824, New York, NY 10278, Phone: (212) 264-1800, Walter Andrews
 - III. 841 Chestnut Street, Philadelphia, PA 19107, Phone: (215) 597-9873, Dale Long
 - IV. 345 Courtland Street, Atlanta, GA 30365, Phone: (404) 347-3633, Wayne Aeronson
 - V. 230 S. Dearborn Street, Chicago, IL 60604, Phone: (312) 353-2650, Ed Watters
 - VI. 1445 Ross Avenue, Dallas, TX 75202, Phone: (214) 655-7155, Thomas Love
 - VII. 726 Minnesota Avenue, Kansas City, KS 66101, Phone: (913) 236-2815, Ralph Langemeir
 - VIII. One Denver Place, 9999 18th Street, Suite 1300 Denver, CO 80202-2413, Phone: (303) 293-1424, Patrick Crotty
 - IX. 75 Hawthorne Street, San Francisco, CA 94105, Phone: (415) 974-8073, Bruce Macler
 - X. 1200 Sixth Avenue, Seattle, WA 98101, Phone: (206) 442-1225, Jan Hastings
- Public hearings will be held in the following locations;

Washington DC—Crystal City Marriott Hotel, 1111 Jefferson Davis Highway, Arlington, VA

Chicago, Illinois—J.C. Kluczynski Federal Building, 230 Dearborn Street, 16th Floor, Chicago, IL

Members of the public who plan to make a statement at either public hearing should contact Danesha Reid to register, EPA (WH-550D), 401 M Street, SW., Washington, DC 20460, telephone (202) 382-7575. Unregistered speakers will be heard after all registered speakers have made their statements.

FOR FURTHER INFORMATION CONTACT:

The Safe Drinking Water Hotline, telephone (800) 426-4791, or Gregory Helms, Drinking Water Standards Division, Office of Ground Water and Drinking Water (WH-550D), Environmental Protection Agency, 401 M Street, SW., Washington, DC 20460, telephone (202) 382-7575.

Abbreviations Used in This Notice

BAT: Best Available Technology
 BEIR: Committee on the Biological Effects of Ionizing Radiation
 CWS: Community Water System
 EMSL: EPA Environmental Monitoring and Support Laboratory (Cincinnati or Las Vegas)
 ede: effective dose equivalent
 GAC: Granular Activated Carbon

ICRP: International Commission on Radiation Protection

MCL: Maximum Contaminant Level
 MCLG: Maximum Contaminant Level Goal

MDL: Method Detection Limit
 Mr/hr: milliroentgen per hour

mgd: Million Gallons/Day
 mrem/yr: millirem/year

NIPDWR: National Interim Primary Drinking Water Regulation

NPDWR: National Primary Drinking Water Regulation

NTNC: Non-transient, non-community water system

pCi/1: picocurie/liter

POE: Point-of-Entry Technologies

POU: Point-of-Use Technologies

PQL: Practical Quantitation Level

PTA: Packed Tower Aeration

PWS: Public Water System

Ra-226: Radium-226

Ra-228: Radium-228

RIA: Regulatory Impact Analysis

Rn-222: Radon-222, or radon

SDWA: Safe Drinking Water Act, or the "Act", as amended in 1986

SMR: Standard Mortality Ratio

WLM: Working Level Month

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I. Summary of Today's NPRM

Applicability

The regulations proposed in this notice would apply to all community and all non-transient, non-community public water systems. The proposed regulations would not apply to private water supplies (i.e., systems serving fewer than 25 persons).

Proposed MCLGs and MCLs

	MCLG	MCL
1. Radium-226.....	zero.....	20 pCi/l.
2. Radium-228.....	zero.....	20 pCi/l.

	MCLG	MCL
3. Radon-222.....	zero.....	300 pCi/l.
4. Uranium.....	zero.....	20 µg/l (30 pCi/l).
5. Beta and photon emitters (excluding Ra-228).	zero.....	4 mrem ede/yr.
6. Adjusted gross alpha emitters (excluding Ra-226, U, and Rn-222).	zero.....	15 pCi/l.

Note: EPA recognizes that most radionuclides emit more than one kind of radiation as they decay. The lists of compounds labeled "alpha" or "beta" emitters identifies the predominant mode of decay.

Note: In this document the unit mrem ede/yr refers to the dose committed over a period of 50 years to reference man (ICRP 1975) from an annual intake at the rate of 2 liters of drinking water per day.

Proposed BATs Under Section 1412 of the SDWA

Radium 226/228: Ion exchange, lime softening, reverse osmosis

Radon: Aeration

Uranium: Coagulation/filtration, ion exchange, lime softening, reverse osmosis

Beta and photon emitters: Ion exchange, reverse osmosis

Alpha emitters: Reverse osmosis

Proposed BAT Under Section 1415 of the SDWA

The same as BAT under Section 1412. Coagulation and filtration and lime softening are not BAT for small systems (those with <500 connections) for the purpose of granting variances because they are not technologically feasible for small systems.

Proposed Compliance Monitoring

(a) The proposed initial monitoring requirements for radon are:

(1) For ground water systems and mixed ground and surface water systems, four consecutive quarterly samples for one year, and then annual samples for the remainder of the first three year compliance period. States could grant monitoring waivers to systems that demonstrate compliance with the MCL reliably and consistently in the initial compliance period, allowing systems to collect only one sample per three year compliance period for the remainder of the nine year compliance cycle. Systems relying solely on surface water are not required to monitor for radon, because radon is a highly volatile gas and is not expected to be found in surface water. Laboratories would be expected to accurately measure radon down to levels of 300 pCi/l at the time of sampling.

(2) Systems that violate the MCL would be required to monitor quarterly

until the average of four consecutive quarterly samples is below the MCL.

(b) The proposed monitoring requirements for gross alpha, radium-226 and uranium are:

(1) Three annual gross alpha screens, to be initiated in the compliance period starting January 1996; if gross alpha is less than the MCLs for radium-226, uranium, and adjusted gross alpha, screening would be reduced to monitoring once per three year compliance period. Laboratories would be expected to measure radium 226 and uranium down to 5 pCi/l and gross alpha down to 15 pCi/l.

(2) If gross alpha exceeds the radium-226, uranium, or adjusted gross alpha MCLs, specific analysis for uranium and/or radium-226 must be conducted. If the contaminant-specific analyses show that the radium-226 or uranium MCL was exceeded, quarterly monitoring for that contaminant is required. If neither MCL is exceeded, monitoring for radium-226 and uranium (or gross alpha screen in lieu of radium or uranium) may be reduced to one sample every 3-year compliance period after 3 annual samples. Sampling may be reduced to one sample every 9-year compliance cycle if the state finds, through a monitoring waiver, that the system meets the MCL reliably and consistently.

(3) Systems that violate the MCL would be required to monitor quarterly until four consecutive quarterly samples is below the MCL.

(c) The proposed monitoring requirements for radium-228 are as follows: Three annual radium-228 analyses would be required; if the radium-228 MCL is exceeded, quarterly monitoring would be required. If the system is consistently below the MCL, then the annual period may be reduced to one sample per three year compliance period. Monitoring may be further reduced to once every 9-year compliance cycle by the issuance of a monitoring waiver if the state finds that the system meets the MCL reliably and consistently. A gross beta test may be used as a screen for radium 228. Systems that violate the MCL would be required to monitor quarterly until four consecutive quarterly samples is below the MCL.

(d) Gross beta monitoring. Only supplies deemed vulnerable to contamination would be required to monitor for beta and photon emitters. Vulnerable systems would be required to measure gross beta quarterly and tritium and strontium annually. The presumptive screen for compliance with the MCL would be 50 pCi/l. Because

only vulnerable systems would be required to monitor, no reduction in monitoring would be allowed. Systems that violate the MCL would be required to monitor monthly until three consecutive samples is below the MCL.

(e) Systems having historical data that has been collected in accord with the analytic chemistry requirements may use the data to determine compliance.

Point-of-use (POU) devices, point-of-entry (POE) devices and bottled water

POE would be allowed to be used to achieve compliance with MCLs; however, POE would not be BAT.

POU and bottled water would not be allowed to be used to achieve compliance with the MCLs; however, either could be, at State discretion, a condition of granting a variance or exemption, except for radon (POU may not be used for radon because POU fails to address radon risks).

Variances and Exemptions

Primacy States may require public water systems to implement additional interim control measures such as installation of additional centralized treatment or POU devices or distribution of bottled water to each customer as measures to reduce the health risk before granting a variance or exemption. The State may not issue a variance or exemption if an unreasonable risk to health exists, as determined by the State using EPA guidance. States must require public water systems to provide POE/POU devices, bottled water or other means, as appropriate to the risks present (i.e., no POU or bottled water for volatile contaminants, such as radon), to reduce exposure below unreasonable risk to health values before granting a variance or exemption. EPA is presently developing guidance for determining affordability to systems serving fewer than 3300 people of different water treatments, for purposes of granting variances. This guidance is expected to be proposed later this year.

II. Background

A. Statutory Authority and Requirements

Section 1412 of the Safe Drinking Water Act, as amended in 1986 ("SDWA" or "the Act"), requires the Environmental Protection Agency (EPA) to publish Maximum Contaminant Level Goals (MCLGs) and promulgate National Primary Drinking Water Regulations (NPDWRs) for contaminants in drinking water which may cause any adverse effect on the health of persons and which are known or anticipated to occur in public water

systems. Under section 1401, the NPDWRs are to include Maximum Contaminant Levels (MCLs) and "criteria and procedures to assure a supply of drinking water which dependably complies" with such MCLs. Under section 1412(b)(7)(A), if it is not economically or technically feasible to ascertain the level of a contaminant in drinking water, the NPDWR may require the use of a treatment technique instead of an MCL.

Under section 1412(b), EPA is to establish MCLGs and promulgate national primary drinking water regulations for 83 contaminants in public water systems. The radionuclides included in today's proposal are among these 83 contaminants.

1. MCLGs, MCLs and BAT

Under section 1412(b)(4) of the Act, EPA is to establish MCLGs at the level at which no known or anticipated adverse effects on the health of persons occur and which allow an adequate margin of safety. MCLGs are non-enforceable health goals based only on health effects and exposure information.

MCLs are enforceable standards which the Act directs EPA to set as close to the MCLGs as is feasible. "Feasible" means feasible with the use of the best technology, treatment techniques, and other means which the Administrator finds available (taking cost into consideration) after examination for efficacy under field conditions and not solely under laboratory conditions (SDWA section 1412(b)(5)). Also, the SDWA requires the Agency to identify the best available technology (BAT) for meeting the MCL for each contaminant.

2. Variances and Exemptions

Section 1415 authorizes the State to issue variances from NPDWRs (the term "State" is used in this preamble to mean the State agency with primary enforcement responsibility, or "primacy," for the public water supply system program or EPA if the State does not have primacy). The State may issue a variance if it determines that a system cannot comply with an MCL despite application of the best available technology (BAT). Under Section 1415, EPA must propose and promulgate its finding identifying the best available technology, treatment techniques, or other means available for each contaminant, for purposes of section 1415 variances, at the same time that it proposes and promulgates a maximum contaminant level for such contaminant. EPA's finding of BAT, treatment techniques, or other means for purposes of issuing variances may vary,

depending upon the number of persons served by the system or for other physical conditions related to engineering feasibility and costs of complying with MCLs, as considered appropriate by the EPA. The State may not issue a variance to a system until it determines that an unreasonable risk to health (URTH) does not exist. EPA has developed draft guidance, "Guidance in Developing Health Criteria for Determining Unreasonable Risks to Health" (EPA 1990k) to assist States in determining when an unreasonable risk to health exists. EPA expects to issue final guidance for determining when URTH levels exist later this year. When a State grants a variance, it must at the same time prescribe a schedule for (1) compliance with the NPDWR and (2) implementation of such additional control measures as the State may require.

Under section 1416(a), the State may exempt a public water system from any MCL and/or treatment technique requirement if it finds that (1) due to compelling factors (which may include economic factors), the system is unable to comply, (2) the system was in operation on the effective date of the MCL or treatment technique requirement, or, for a newer system, that no reasonable alternative source of drinking water is available to that system, and (3) the exemption will not result in an unreasonable risk to health. Under section 1416(b), at the same time it grants an exemption the State is to prescribe a compliance schedule and a schedule for implementation of any required interim control measures. The final date for compliance may not exceed three years after the initial date of issuance of the exemption unless the public water system establishes that: (1) The system cannot meet the standard without capital improvements which cannot be completed within the period of such exemption; (2) the system has entered into an agreement to obtain financial assistance for necessary improvements; or (3) the system has entered into an enforceable agreement to become part of a regional public water system. For systems that serve 500 or fewer service connections and which need financial assistance to come into compliance, the State may renew the exemption for additional two-year periods if the system is taking all practicable steps to meet the above requirements.

3. Primacy

As indicated above, States may assume primary enforcement responsibility (primacy) for public water

systems under section 1413 of the SDWA. To assume or retain primacy, States need not adopt the MCLGs but must adopt, among other things, NPDWRs that are no less stringent than those EPA promulgates. States may also, at their discretion, adopt standards more stringent than the NPDWRs.

4. Monitoring, Quality Control, and Recordkeeping

Under section 1401(1)(D) of the Act, NPDWRs are to contain "criteria and procedures to assure a supply of drinking water which dependably complies with such maximum contaminant levels; including quality control and testing procedures to insure compliance with such levels * * *." In addition, section 1445 (a)(1) states that "every person who is a supplier of water * * * shall establish and maintain such records, make such reports, conduct such monitoring and provide such information as the Administrator may reasonably require by regulation to assist him in establishing regulations * * * in evaluating the health risks of unregulated contaminants, or in advising the public of such risks." Section 1445 also requires EPA to promulgate regulations requiring every public water system to conduct a monitoring program for unregulated contaminants, and EPA has established a number of specific requirements.

5. Public Notification

Section 1414(c) of the Act requires the owner or operator of a public water system which fails to comply with an applicable maximum contaminant level or treatment technique requirement, testing procedure, or section 1445(a) monitoring requirement to give notice to the persons served by the water system. Owners and operators of public water systems for which variances or exemptions are in effect, or which fail to comply with the requirement of any schedule assembled pursuant to a variance or exemption, must also give notice. Section 1445(a)(5) also requires public water systems to notify the persons served by the water system and the Administrator of the EPA of the availability of the results of monitoring for unregulated contaminants. Public notification regulations are codified at 40 CFR 141.32.

B. Applicability

These proposed regulations would apply to all community water systems (CWSs) and all non-transient, non-community public (NTNC) water systems.

Public water systems are defined in the Act as those systems which provide

pipled water for human consumption and have at least 15 connections or regularly serve at least 25 people. Section 1401(1)(D)(4). The category "public water system" is composed of community and non-community water systems. A community water system is one which serves at least 15 connections used by year-round residents or regularly serves at least 25 year-round residents (40 CFR 141.2). Non-community systems, by definition, are all other public water systems. Non-community systems include transient systems (e.g., restaurants and service stations having independent water sources) and non-transient systems which EPA has defined as facilities that have their own water supply and regularly serve at least 25 of the same persons for at least six months a year (see 52 FR 25712, July 8, 1987).

Transient non-community water systems would not be covered by these proposed regulations. Environmental levels of these contaminants pose public health hazards over a long period of exposure. Occasional and infrequent exposure to environmental levels of these contaminants pose minimal risks to the public and do not warrant regulation under the SDWA.

EPA solicits public comment on the application of these regulations to community and non-community nontransient public water supplies.

C. Regulatory Background

In 1976, EPA promulgated the National Interim Primary Drinking Water Regulations (NIPDWRs) for combined radium-226 and radium-228 at 5 pCi/l, gross alpha particle emitters at 15 pCi/l, and beta particle and photon emitters (also referred to as the "man-made" radionuclides) at a total dose equivalent of 4 mrem/year to any organ or whole body (40 CFR 141.15). These levels are currently in effect and enforceable. When these NIPDWRs were developed, the Agency did not have sufficient health and occurrence data on uranium and radon to develop standards. Therefore, there are no existing primary drinking water regulations for these two radionuclides. As part of an effort to develop better information for these regulations, EPA sponsored a workshop on radioactivity in drinking water (Health Physics, 1985).

On September 30, 1986, EPA published an advance notice of proposed rulemaking (ANPRM), (51 FR 34836, Sept. 30, 1986) concerning the radionuclides contained in today's proposed action. The ANPRM discussed EPA's understanding of the occurrence, health effects, and risks from these radionuclides, as well as the available

analytical methods and treatment technologies and sought additional data and public comment on EPA's planned regulation. This notice builds on and updates the information assembled for the 1986 ANPRM.

The information in the ANPRM on occurrence was estimated from the nationwide compliance data for the standards in place, several nationwide and regional studies, and State data bases. Although the occurrence data for uranium and radon were not as complete as for the other regulated radionuclides, the available data showed that uranium, radium, and radon are seldom found together in high concentrations. Relatively higher levels of radium were found in the midwest and Appalachian region, natural uranium in the Rocky Mountains, and radon in the northeast. When the ANPRM was published the available data indicated that radon and uranium generally were distributed at low levels in water supplies throughout the United States. In some areas, however, ground water supplies had much higher levels of radon. Compliance monitoring data on radium indicated moderate occurrence, primarily in the midwestern states. Beta particles and photon emitters were not detected above the 50 pCi/l screening levels.

The ANPRM summarized the types of cancer associated with each radionuclide, the toxic effects of uranium on the kidney, and the estimated annual national risks posed by each radionuclide in drinking water. Several analytical methods were mentioned and were presented along with treatment technologies and estimated costs.

D. Comments by the Science Advisory Board and the Public on the ANPRM

1. SAB Comment

The EPA's Science Advisory Board's (SAB) Radiation Advisory Committee (RAC) reviewed the ANPRM and the four draft criteria documents which supported it prior to publication of the ANPRM in the *Federal Register* (51 FR 34836; September 30, 1986). EPA subsequently revised the criteria documents and resubmitted them to the SAB/RAC for review during the summer of 1990. EPA has now revised the criteria documents based on this latest review (SAB/RAC, 1990) and presents a summary of the SAB/RAC comments and EPA's replies to them here. More detail on these issues may be found in the latest revised criteria documents themselves.

a. *General comments and generic issues.* In requesting review of the health criteria documents in 1990, the EPA requested the SAB/RAC to focus on five questions in their review, in addition to providing any additional comments the reviewers believed to be relevant. The five questions asked were:

1. Are the estimates of the absorption, distribution and excretion of uranium, when ingested, appropriate and supported by the data?

2. Do the estimates in the documents form an appropriate basis for assessing the risks of directly ingesting water containing radon?

3. What is an appropriate basis for estimating the risks from radon in water?

4. What relative emphasis should be placed on the epidemiology data and modeled risk estimates for evaluating radium risks?

5. Is the methodology for assessing risks from man-made radionuclides (both individually and collectively) appropriate?

The SAB/RAC reviewers also commented on the overall quality of the draft documents and commented on several additional subjects.

The SAB/RAC comments were organized as follows: General Comments and Generic Issues; Responses to the Five Specific Questions; and Comments on Important Issues in the Criteria Documents and Related Reports. EPA's replies to these comments follow the SAB/RAC organization, and are as follows:

a=1. *General comments and generic issues.* The SAB/RAC made the following general comments:

1. The general quality of the documents was not good.

EPA Reply: Full criteria documents, rather than only Quantification of Toxicological Effects sections, have been prepared, with careful review by ORP and ODW. Irrelevant information and incorrect definitions have been deleted, and definitive descriptions of the dosimetric models have been included in each Criteria Document. Except where noted in the Criteria Documents, the bases for selecting models is the same as those given by the ICRP in their publication ICRP 30 (ICRP 1979). Material on chemical and physical properties has been included, consistent with OW format for preparation of Criteria Documents. The five documents have been made consistent in their approaches to risk assessment. Comments by the SAB/RAC made during the 1987 review have been considered and addressed in the revised Criteria Documents. EPA believes the overall quality of the revised documents

is substantially improved, and will continue to update the documents, as needed, between proposal and promulgation of this regulation.

2. Technical decisions contrary to SAB and NAS recommendations were presented without discussion of alternatives or justification for the Agency's choices.

EPA Reply: Detailed discussions are provided in the criteria documents of issues raised by the SAB, as indicated for document-specific comments below. The basis for adoption of SAB and NAS recommendations is presented in individual criteria documents and described briefly below. EPA's adoption of advice and guidance has attempted most appropriately resolve potentially conflicting recommendations, and strives to be consistent both internally and with other Federal Agencies in its assessments of radiation risks. EPA's modification of the ICRP dosimetric models is used for assessing doses and risks from radium, uranium and gross alpha emitters, and for estimating doses used in calculating the effective dose equivalent, which serves as the basis of the standard for beta and photon emitters.

3. Uncertainties were not adequately addressed.

EPA Reply: A new chapter has been added to each criteria document addressing uncertainties associated with the range of assumptions and models considered and those arising from parameter variability (chapter IX in each document).

b. *Responses to the five specific questions.*

1. Are the estimates of the absorption, distribution and excretion of uranium, when ingested, appropriate and supported by the data?

The SAB/RAC believed the absorption, distribution and excretion estimates presented in the draft uranium criteria document needed to be discussed in more detail and better supported by the criteria document. In particular, the SAB/RAC disagreed with use of 0.20 as the f_1 (gastrointestinal absorption factor) and cited a 1985 review sponsored by the EPA as recommending an f_1 value of 0.014. SAB/RAC also urged that the value chosen be identified as representing the average population or any special sensitive groups.

EPA Reply: EPA has extensively reviewed the literature available on this issue and believes that a value of 0.05 is appropriate. However, published studies present a wide range of possible values for the uranium uptake factor. While EPA believes a value of 0.05 is supportable based on the literature, the

uncertainty associated with this value may be great, perhaps a factor of 4 greater or less than the value chosen. The basis for this uncertainty assessment is presented in the revised uranium health criteria document. EPA believes 0.05 to be a best estimate for the general population, and not a highly conservative value for the f_1 factor.

2. Do the estimates in the documents form an appropriate basis for assessing the risks of directly ingesting water containing radon?

The SAB/RAC urged EPA to better justify use of a fresh tap water consumption value of 0.66 liters/day, a value different than the 2 liters daily consumption usually used in assessing exposure to drinking water contaminants, and other assumptions about radon loss from water during consumption. The SAB/RAC also noted that the approach used for assessing the risks of radon in drinking water differs from that used for assessing risks from other volatile contaminants in drinking water.

EPA Reply: A separate document was prepared by EPA to describe the data available for both the selected rate of ingestion and for radon loss during water consumption, and the rationale for the selected values. Consistency with previous regulations of volatile contaminants in drinking water is also addressed. These points are summarized in the Radon Criteria Document (sections IV.C.1 and VIII.B.2) and the uncertainties are discussed in chapter IX of the Radon Criteria Document (section IX.B.1).

The available data on tap water consumption is presented in "Radon in Drinking Water: Assessment of Exposure Pathways" (EPA, 1991h). EPA continues to believe a value other than 2 liters per day is appropriate for assessing risks from ingested radon, and has used a value of 1 liter daily intake of fresh tap water, as a reasonable maximum, in the revised documents. EPA believes this is appropriate because radon is a volatile gas and will not be present in water used for cooking or making tea or coffee, or water that has been standing for some time. EPA has therefore estimated consumption of water that is promptly consumed, i.e., water drawn from the tap and consumed immediately, for assessing radon exposure via the ingestion route. EPA has previously used the 2 liter daily water consumption estimate in assessing risk for other volatiles in drinking water because no separate inhalation exposure and risk assessment was performed. The exposure to other volatile contaminants via ingestion

predicted by 2 liters daily consumption served as a surrogate to compensate for the lack of a separate inhalation exposure and risk assessment. Because there are data on the transfer of radon from water to the indoor air of homes, an exposure assessment by the inhalation route for radon derived from water can be made. EPA has estimated the inhalation exposure and risk and the ingestion exposure and risk resulting from radon in water separately, and added the two assessments together in estimating overall risks from radon in water. The radon exposure pathways document also describes the basis for estimating 20% loss of radon from water before it is consumed.

3. What is an appropriate basis for estimating the risks from radon in water?

The SAB/RAC asserted that use of a generic tap water to air transfer factor overlooks potential high radon concentrations at the point of release, such as during showering, and urged inclusion of such an exposure assessment in the revised documents. SAB/RAC stated that all contributions to total exposure should be considered, and that uncertainties in all the estimates must be addressed. SAB/RAC also stated that there were differences in the draft criteria document from a draft radon risk assessment previously submitted to SAB/RAC by EPA's ORP for review.

EPA Reply: An analysis of exposure to radon during showering and other household uses of water was performed by EPA and is presented in "Radon in Drinking Water: Assessment of Exposure Pathways" (EPA, 1991h). The analysis was summarized in the Radon Criteria Document (sections IV.C.2 and VIII.B.2) and the uncertainties are discussed in chapter IX of the Radon Criteria Document (sections IX.A.3 and IX.B.2).

This document reviews the available data and methods for evaluating inhalation exposure to radon released from water. These include several empirical studies as well as several modeled approaches to exposure assessment. EPA concluded in this analysis that although mass balance modeling can be performed for radon from showering and other water use, assessing risk based on this information is difficult. Human activity patterns are highly variable with regard to factors that have a large influence on exposure, such as temperature and length of shower, shower flow rate, timing of multiple showers within a household, and location and use of clothes washing machines. Also, significant unanswered questions remain about the equilibrium

of radon with its progeny in the shower and bathroom, the unattached fraction, and aerosol particle size in a shower and behavior of water aerosols in the respiratory tract. Modeling does allow for risks from showers to be broadly bounded, and EPA has done so in its review. EPA concluded that integrated exposure and risk estimates developed from modeled water use through out the house (including showering) differ only slightly from the results obtained from use of an average water to air transfer factor such as 10,000:1 (i.e., 10,000 pCi/1 radon in water increases indoor air levels by about 1 pCi/1), based on the empirical data.

In response to the final point of the SAB/RAC, there is no overall quantitative difference in the risk assessment presented in the draft Radon Health Criteria Document and the draft submitted to the SAB for review in February of 1990. Both present the average unit risk value of 360 deaths per 10^6 working level months of exposure to radon and its progeny, in air, as a central estimate, consistent with EPA's letter of November 23, 1988 (EPA, 1988f) to the SAB/RAC, which first used this as the unit risk for radon. The source of disagreement was apparently the lack of separate presentation of risks to smokers and nonsmokers. Risks to smokers and non-smokers were not presented separately and in detail as in the February 1990 paper. EPA has added this discussion to the revised Radon Criteria Document (sections VI.C and VIII.B.2, Table VI-1). The preparation of the Radon Criteria Document was coordinated with the evolving ORP position on indoor radon risks to the extent the regulatory and review schedules allowed, and EPA will continue to update the document, as needed, between proposal and promulgation of the final rules.

4. What relative emphasis should be placed on the epidemiology data and modeled risk estimates for evaluating radium risks

The SAB/RAC urged EPA to base its risk assessment for radium on human epidemiology data on radium watch dial painters, rather than on modeled estimates, and urged EPA to present its rationale for adopting the modeling approach for radium risk assessment. The SAB/RAC also requested that EPA better describe its dosimetric model in the revised criteria document, including calculated doses and risks to organs, and that if EPA continued to use the modeling approach, uncertainties in the modeling be addressed.

EPA Reply: The Agency carefully reconsidered this issue. First it should be pointed out that all risk estimates are

based on both epidemiologic data and require mathematical modelling. The EPA uses the wealth of epidemiologic data on human exposure and risk of radiogenic cancers, including radium dial painters and epidemiologic data on bone sarcomas resulting from injected Ra-224.

The watch dial painter data indicate that the incidence of bone sarcomas may follow a dose-squared response, especially at higher exposures. EPA policy, supported by recommendations of SAB/RAC, is to assess cancer risks from ionizing radiation as a linear response. Therefore, use of the dial painter data requires either deriving a linear risk coefficient from significantly non-linear exposure-response data, or abandoning EPA policy and SAB/RAC advice in this case. Two analyses were recommended as alternatives by the SAB/RAC, those of Mays et al. (1985) and of Schlenker (1982). Both analyses used the same cohorts, calculated doses and definitions of incidence, and differed primarily in the statistical approach to deriving a linear slope that would not be rejected by the epidemiology data. The two resulting values differ by about 60%. EPA was not able to determine whether this degree of agreement resulted from the use of identical data, but took into account the caution of the BEIR IV Committee (NAS, 1988) that there was no unique way to derive a linear risk coefficient for bone sarcomas from the dial painter data.

There are, however, serious problems in applying the watch dial painter epidemiologic data. These include uncertainties in intake, due to variability in retention of radium and to lack of measurement of Ra-228. There may also be uncertainty in these data due to possible bias in identification and measurement of workers, and the lack of a unique way to specify the appropriate extrapolation of the observed quadratic response among workers at high intakes with known abnormal bone physiology to a linearized response consistent with the lack of observed sarcomas among lower-intake cohorts. There may also be problems in extrapolating to continuous intakes across years from a single intake, and in assessing latency and duration of plateau based on the radium-224 data. The dial painter data and the issues involved in extrapolation are extensively discussed in the Radium Criteria Document (sections III.B, VI.B.1, VIII.B.2, IX.A.1 and IX.A.2, Tables VI-1 to VI-3, VIII-1 and VIII-2), and a thorough discussion of the RADRISK model has been incorporated (sections III.D, VII.B, VIII.B.2, IX.A.2 and IX.B.2, Tables III-1 and VIII-3 to VIII-5).

An alternative to the dial painter data for deriving a linear coefficient is the experience with patients injected with a short lived isotope of radium. The BEIR III committee (NAS, 1980) found that these epidemiology data were consistent with a linear relationship between dose and bone sarcoma incidence, and derived a linear risk coefficient. Because of the difference in the toxicokinetics between the short-lived and the long-lived isotopes of radium, modelling is required to use the BEIR III risk coefficient. The use of models introduces some uncertainty into the assessment of risk but has the advantage that differing patterns of exposure can be evaluated (e.g. constant lifetime exposure).

The RADRISK model (Sullivan et al., 1981; Dunning et al., 1980; EPA, 1989a) used by EPA to assess risk from radionuclides also allows calculation of radiologic doses to and cancer risks in organs other than bone, based on epidemiology data on cancer risks from several studies of effects of ionizing radiation.

One concern the SAB/RAC had with this model was that the predicted incidence of leukemias was higher than observed in the dial painter cohorts. EPA reexamined this prediction and revised the calculation of the high-LET radiation risk to bone marrow to be more consistent with the predictions of the watch dial painter study and the observations in the spondylitic and Thorotrast studies. The predictions of the RADRISK model were adjusted to give a relative incidence of leukemias and bone sarcomas more consistent with observed data, which is also more consistent with the watch dial painter data (as described in section VIII.B.2, Table VIII-5 of the revised criteria document). Data on the leukemia incidence reported in patients injected with Thorotrast, a thorium-based radiologic contrast agent were also examined (NAS 1988). EPA has also added head carcinoma risk to the model (for radium-226), consistent with the watch dial painter studies.

As a result of this reconsideration EPA continues to incorporate the estimate of the bone sarcoma risk coefficient derived from epidemiology data that show a linear dose-response curve (the data for radium-224), a revised bone marrow risk coefficient and hence leukemia risk, and has added a risk coefficient for radium-226 induced head carcinomas. These issues and EPA's conclusions are discussed in the revised radium health Criteria Document, and as requested by SAB/RAC, an expanded description of the

RADRISK model and assessment of uncertainties have been added.

5. Is the methodology for assessing risks from man-made radionuclides (both individually and collectively) appropriate?

The SAB/RAC urged EPA to include risks from man-made alpha emitters as well as beta emitters, urged use of EPA "official" risk estimates, and urged that the results be presented without reference to likely regulatory levels.

EPA Reply: EPA has revised its risk assessment numbers to correspond to previous estimates generated by the RADRISK model, and will incorporate any revisions based on the recommendations of the BEIR V report only after SAB/RAC has had an opportunity to review and comment on them as a separate issue and not in the context of this proposed regulation. Similarly, only unit risk and dose assessments are presented in the revised criteria document, without reference to possible regulatory levels.

c. *Comments on important issues in the criteria documents.* SAB/RAC also made the following comments on the draft Criteria Documents:

i. *Uranium criteria document.* 1. The document fails to explain selective adoption of the recommendations of the BEIR IV report, in particular the BEIR IV use of analogy with radium as the basis for risk evaluation of uranium, and the BEIR IV conclusion that any cancer risk from uranium is from bone sarcoma, not other organs as predicted by the EPA model.

EPA Reply: For a number of reasons discussed above, EPA has continued to rely on its risk model for assessing radium cancer risks, and uses this approach for assessing uranium cancer risks as well. EPA, like the ICRP, evaluates dose and risk for a number of organs and tissues and combines them as appropriate to obtain the risk estimate. EPA believes that all emitters of ionizing radiation are carcinogenic. EPA has reviewed and revised a key parameter value used in this model, the f_1 value, according to SAB/RAC recommendations, and has also revised the predicted risks of leukemia, as described above for radium, and the risks to kidney. These revisions are discussed in greater detail in sections IV and VIII of the revised uranium Criteria Document.

2. The uncertainty in the risk assessment for uranium must be discussed.

EPA Reply: An analysis of the uncertainties in the uranium cancer risk estimate has been prepared and is

presented in section IX of the revised uranium Criteria Document.

3. If a modeled approach is chosen, EPA must justify selection of the models and parameter values, in particular the f_1 value of 0.20 used in the draft criteria document, and the work of Wrenn et al. (1985) and Spencer et al. (1990; as cited in EPA, 1991e) must be addressed. Quality of the data and the possible effect of diet and eating habits on the uptake of uranium must be considered.

EPA Reply: As discussed above, EPA has reviewed and revised the f_1 value used in estimating uranium risks. The work of Wrenn et al., and Spencer et al., were considered in this review. Evaluation of the data quality and the possible effect of diet and habits, i.e., iron deficiency and the "no-breakfast syndrome," are presented in the uncertainty discussion of the revised Uranium Criteria Document.

4. Comments and recommendations of the 1987 Drinking Water Subcommittee review have not been incorporated into the document, and the document includes irrelevant information (on inhalation studies) and some incorrect definitions.

EPA Reply: EPA has reviewed the comments made by the 1987 Committee review, and addressed those that remain pertinent to the revised documents. Studies by exposure routes other than ingestion have been included in the Criteria document, where those studies indicate systemic effects and especially where data by the ingestion route are sparse. Terms and definitions have been reviewed and corrected where found to be incorrect.

ii. *Radium criteria document.* 1. Extrapolation of risk from dial painter data.

EPA Reply: This issue is addressed in question number 4 above.

2. Uncertainties are not adequately addressed.

EPA Reply: EPA has added an assessment of the uncertainties in the risk evaluations to all of the revised Criteria Documents.

3. The estimate of radium absorption from Maletskos et al. (1966) should be discussed further and uncertainties addressed.

Response: The discussion has been expanded (section III.A) and uncertainties are addressed (section IX.B.1).

4. The issue of sensitivity of children to non-cancer effects of radium should be revised.

Response: This recommendation was followed (sections III.B, VI.C, VIII.A and IX.A.1).

5. The RADRISK model should be described in more detail, and the over-prediction of leukemias, lack of prediction of head carcinomas, and relative risks of Ra-226 and Ra-228 should be addressed.

EPA Reply: This recommendation was followed (sections III.D, VII.B, VIII.B.2, IX.A.2 and IX.B.2, Tables III-1 and VIII-3 to VIII-5 of the radium Criteria Document). As described above, the estimates of leukemia risk for radium 226 and 228 have been revised and the head carcinoma risk for radium-226 added, consistent with the watch dial painter data. Organ doses and risks to bone and other organs are also presented. On review, EPA discovered an error in the estimated radium-228 dose to bone marrow and bone surface, and has revised the dose, and hence risk estimate for radium-228 to be consistent with the dose estimated by the ICRP 30 model (EPA, 1991b). It should be noted that the 2.5 fold higher potency of radium-228 in inducing bone sarcomas among the watch dial painters relates to an instantaneous intake of radium, and less of a difference would be expected for continuous lifetime exposure (Rowland et al., 1978).

iii. *Documents related to radon.* 1. Inconsistencies in the relative conservativeness of the assumptions across the criteria documents for radionuclides and with regulation of other volatile chemicals in water should be addressed.

EPA Reply: Parameter values used in the criteria documents have been reviewed and are now more consistent with regard to their degree of conservativeness.

As discussed above, radon is the first drinking water contaminant for which the inhalation pathway is specifically addressed as a separate exposure pathway. This involves adjusting the ingestion risk downwards to account for loss of radon from tap water used for cooking and in other ways that would cause radon loss (making coffee, tea, etc.) and also separately quantifying inhalation exposure from all household uses of water. The Agency made an extensive analysis of the exposure to radon by ingestion and by inhalation of radon released from household uses of water, including short-term exposure during showering. This analysis is presented in a separate document (EPA 1991h) and summarized in the Radon Criteria Document (sections IV.C.1, IV.C.2, VIII.B.2, IX.A.3, IX.B.1 and IX.B.2).

2. Uncertainties should be discussed, particularly of variability of important parameters in the risk assessment.

Response: Chapter IX of the Radon Criteria Document addresses uncertainties both from the range of assumptions and models and from parameter variability.

3. The discussion of radon health risks should be updated and made consistent with the ORP approach, and the appendix discussions of non-cancer health effects of radiation exposure should be omitted.

EPA Reply: The discussion of miner data, including Lubin et al. (1990, as cited in EPA, 1991c), has been updated (Radon Criteria Document section VI.B.2) and risks of inhaled radon decay products have been listed separately for smokers and nonsmokers (sections VI.C and VIII.B.2, Table VI-1). Genetic effects are discussed in the Radon Criteria Document (sections VI.B.1, VI.B.2, VIII.C, IX.A.4 and IX.B.3, Tables VIII-7 to VIII-9) because these may be relevant in the context of radon in drinking water.

4. The basis for the rate of consumption of tap water and the loss of radon should be presented and defended.

EPA Reply: This has been done in a separate document (EPA 1991h) and summarized in the Radon Criteria Document (sections IV.C.1, VIII.B.2 and IX.B.1).

5. The basis for the selection of the transfer factor for waterborne radon contribution to indoor air radon levels should be presented and defended.

Response: This has been done in a separate document (EPA 1991h) and summarized in the Radon Criteria Document (sections IV.C.2, VIII.B.2 and IX.A.3 and IX.B.2).

6. The daily acute exposure from showering should be considered, including the degree of radon equilibrium.

EPA Reply: This has been done in a separate document (EPA 1991h) and summarized in the Radon Criteria Document (sections IV.C.2, VIII.B.2 and IX.A.3 and IX.B.2).

7. Additional analysis of the ingestion model by Crawford-Brown (1990) would be useful, including extending the analysis of uncertainty.

EPA Reply: The analysis of uncertainty in radon ingestion risks is extended in the Radon Criteria Document (sections IX.A.2 and IX.B.1). The model of Crawford-Brown (1990), which has been published in peer-reviewed journals (*Risk Anal.* 11:135-143, 1991), was considered to be the best analysis available for assessing risks of ingested radon.

8. The document should not contain incorrect definitions of fundamental technical terms or basic fallacies.

EPA Reply: The Radon Criteria Document has undergone extensive internal Agency review to correct inaccurate terminology.

iv. *Manmade Radionuclides Document.* 1. The document on manmade radionuclides used risk factors inconsistent with the other radionuclides discussed here and used an ad hoc extrapolation of risk factors based on an assessment of the BEIR V report that has not been submitted for review by the SAB, in spite of a previous agreement to do so.

EPA Reply: As described above, EPA's established risk factors have been used in the revised Criteria Document. Use of risk factors based on the BEIR V report will be delayed until EPA has reviewed these with the SAB/RAC in a separate evaluation.

2. The evaluation of risks should be based on the ICRP effective dose equivalent concept.

EPA Reply: EPA has used its own dosimetric model (the RADRISK model), based to a large degree on ICRP models and parameters, in the revised criteria document on beta and photon emitters.

3. The document should define the potential risks of exposure, rather than define the regulatory value of 4 mrem ede/yr.

EPA Reply: The revised beta and photon emitter Criteria Document assesses risks and does not present a regulatory value. Regulatory values for the beta and photon emitters, based on the unit risks in the Criteria Document, are presented in appendix B of this notice.

4. The document fails to adequately discuss uncertainties associated with the values of parameters selected and overall uncertainty of the evaluation.

EPA Reply: An assessment of the uncertainties in the risk estimates has been added to each of the Criteria Documents.

5. Tables A-1 and V-1 are misleading or difficult to understand as presented.

EPA Reply: These tables have been revised to clarify the information presented in them.

2. Public Comment on the ANPRM

EPA requested comments on all aspects of the September 30, 1986 ANPRM. A summary of the major comments, and the Agency's response to the issues raised, are presented below. A detailed enumeration of the comments received and the Agency's responses is presented in the document "Response to Comments Received on the NPDWRs: Radionuclides in Drinking Water—Advanced Notice for Proposed Rulemaking of September 30, 1986,"

(EPA, 1991j) which is available in the public docket for this rulemaking.

EPA received 44 written comments on the ANPRM. Of the comments received, 2 were from individuals, 2 were from Federal agencies, 11 were from States, 3 from local governments, 15 were from companies, 4 were from public water supplies and 8 were from public or professional organizations.

EPA held a public hearing on November 13, 1986. Representatives of a professional organization and of a company each made a statement and two local government representatives reported on levels of radionuclides in their water.

Because some of EPA's approaches to risk evaluation and regulation have been revised since 1986, some of the comments and issues are addressed only in the comment response document. Those still considered significant are discussed here.

a. *EPA's proposal to set a MCLG and MCL for natural uranium.* A total of 16 commenters addressed EPA's advanced notice for regulating uranium.

Commenters raised four major issues regarding the uranium regulation:

- (1) Toxicity Versus Carcinogenicity
- (2) No-Observed-Adverse-Effect-Level
- (3) Risk Estimates
- (4) Economic Impact

(1) Uranium toxicity versus carcinogenicity

Comments: Ten commenters questioned EPA's proposal on the basis of insufficient scientific evidence to show that natural uranium is a carcinogen. One commenter disagreed with EPA's rationale to regulate uranium based on similarities to radium and another maintained that EPA's comparison of radium and uranium was flawed because EPA ignored the fact that uranium will expose tissues at a much lower dose and dose rate. In support of EPA's proposal, one commenter urged EPA to set MCLGs at zero because of the lack of available data on the radiotoxic effects of uranium and because of similarities between radium and uranium.

EPA Response: Uranium, like radium, is a source of ionizing radiation which decays and emits alpha particles internally, thereby irradiating internal tissues. Uranium also concentrates in bone as does radium, and kidney. Ionizing radiation has been shown in many studies to be carcinogenic in humans and EPA has classified it as a group A carcinogen. Uranium has caused cancers at multiple sites in laboratory animals, as would be expected from a source of ionizing radiation. Furthermore, the human carcinogenic risk from ingested radium

is well-established (EPA, 1991b). For these reasons, the Agency is proposing to establish an MCLG for natural uranium based on it being a carcinogen. Uranium also is believed to be toxic to the kidneys, and below, EPA discusses exposure levels that would be considered safe for this adverse effect. In setting a standard, EPA will ensure that the eventual MCL is protective for both the carcinogenic potential of uranium and for kidney toxicity. For the purposes of this rule the MCL is based on uranium's potential for kidney damage.

Comment: One commenter stated that information presented at the National Workshop for Radioactivity in Drinking Water held in May 1983, indicated that carcinogenic risks were negligible from uranium, as well as from radium and radon.

EPA Response: The risk level estimated in the 1983 Workshop on uranium was 6×10^{-7} per pCi/l lifetime cancer risk (Mays et al., 1985). Since the 1983 Workshop, EPA has continued to assess the hazards of all the contaminants in this proposed rule. The Agency still believes the risk from uranium to be approximately 6×10^{-7} per pCi/l (EPA, 1991e). EPA does not regard this risk as negligible. Longstanding and carefully considered EPA policy for regulating carcinogens in drinking water is that the lifetime individual risk target is one in 10,000 (10^{-4}) to one in 1,000,000 (10^{-6}) risk. As uranium occurs in water used as a source of drinking water at levels posing risks within this target range, the Agency believes regulation is warranted. Uranium is also toxic to kidney at concentrations that may be found in drinking water, and protection against this potential hazard is also warranted. In addition, regulation of uranium in drinking water is required by the 1986 amendment to the SDWA.

(2) No-Observed-Adverse-Effect-Level

Comments: Two commenters cited data showing that the lowest concentration of uranium shown to cause kidney damage is 3 μ g per gram of kidney with 1 μ g/gram kidney being a kidney concentration well below the level causing kidney damage. The commenter stated that this concentration in water is approximately equivalent to an exposure of 1,00 pCi/l. Another commenter believed there is no reason to develop a regulatory limit for uranium of less than 5 mg/l, asserting that 5 mg/l is the accepted, nontoxic level for natural uranium from heavy metal toxicity.

EPA Response: The study that the first commenter is referring to (Wrenn et al.,

1985) goes on to derive an intake limit for uranium in drinking water based on the 1 μ g per gram of kidney as a no-toxic-effects concentration level. Using a GI absorption estimate of 1.4% for humans at environmental levels of uranium intake, a safety factor of 50, and a 1.71 l/day water intake, the study recommends a 100 μ g/l limit for uranium in drinking water.

Based on evidence from a number of chronic and subchronic toxicity studies with several species of animals, EPA has identified a lowest-observed-adverse-effect-level (LOAEL) of 2.8 mg uranium/kg/day based on moderately severe renal damage following 30 days of dietary administration of uranyl nitrate to rabbits (EPA, 1991e). From this LOAEL, the Agency calculated a reference dose (RfD), or daily exposure for humans likely to be without appreciable risk of adverse health effects during a lifetime. The RfD is 3×10^{-3} mg/kg/day (EPA, EPA, 1991s).

When estimating drinking water contaminant levels for contaminants or effects associated with identified thresholds, EPA calculates a Drinking Water Equivalent Level (DWEL), a drinking-water specific lifetime exposure for the contaminant at which adverse non-carcinogenic health effects are not anticipated to occur. This DWEL for uranium was calculated to be 0.10 mg/l (or 100 μ g/l) using kidney toxicity to adults as an endpoint. When setting an MCLG based on an identified threshold, the DWEL is multiplied by the relative source contribution (RSC) for water (the fraction of total exposure that derives from drinking water) to form the basis for the MCLG. EPA examines the available data on other exposure sources to identify the RSC, and uses a value of 20% as a default value if data are not available or are of poor quality; that is the case with uranium. This would give an MCLG of 20 μ g/l, or approximately 30 pCi/l. This level is well below the level cited by the second commenter as an accepted, nontoxic level for natural uranium. These issues are discussed in greater detail in Sections III. and IV. below.

(3) Risk Estimates

Comment: One commenter stated that EPA's risk estimates for uranium are flawed because they were developed using a linear dose-response curve that overestimated risk from lifetime exposure to water supplies having up to 100 pCi/l of uranium. This commenter urged EPA to consider the BEIR IV report which contains information concerning the extrapolation of the

biological effects of all alpha emitters, including uranium.

EPA Response: The BEIR III report (NAS, 1980) recommends linear dose response curves for use in assessing risks from all alpha emitters, and as appropriate for uranium, since it is an alpha emitter. The BEIR IV (NAS, 1988) report makes no clear recommendation, but rather discusses the implications of making different choices among the possible alternative approaches.

(4) Economic Impact

Comments: Two commenters argued that the cost of treatment for uranium is too high, especially for small water systems, considering the lack of data showing that uranium is carcinogenic.

EPA Response: As stated above, EPA believes that there is adequate scientific evidence to show that uranium is carcinogenic to humans.

Costs for uranium removal are dependent on water system size, concentration of uranium in source water, and the type of removal treatment used. EPA has determined that proposed BATs for uranium removal are affordable by regional and large public water systems (EPA, 1991i). EPA also evaluates total, or national compliance costs as well as household costs and cost-effectiveness in assessing feasibility of treatment. EPA considers the cost of the health protection afforded by the proposed MCLs to be reasonable (EPA, 1991i). While affordability assessments are based on cost to regional and large water systems, variances and exceptions may be available for some small systems if required conditions are met (i.e., see section V.I). Variances or exemptions may not be granted if doing so would result in an unreasonable risk to health. The Agency has specified proposed BATs for variance purposes for small water systems (see section V.B) and is continuing to evaluate what costs are reasonable for public water systems.

b. **EPA's proposal to set separate MCLGs and MCLs for radium-226 and radium-228.** A total of 11 commenters submitted comments regarding the appropriateness of establishing combined or separate MCLGs and MCLs for radium-226 and radium-228.

Comments: Most commenters on this issue supported the establishment of separate MCLGs and MCLs for the two contaminants, citing several reasons: each appears to be different toxicologically, each has different degrees of biological effectiveness, and each has different risk levels associated with identical concentrations.

In opposition to separate MCLGs and MCLs for radium-226 and radium-228,

one commenter maintained that the database for radium-228 is insufficient to warrant separate regulations for the two isotopes.

EPA Response: The Agency does not agree that the database for radium-228 is insufficient to warrant separate regulation. There is sufficient scientific evidence that carcinogenic risks from radium-228 are not qualitatively different from radium-226 risks (EPA, 1991b).

As discussed above, and in detail in the revised health criteria document for radium, EPA has classified radium-228 as a group A human carcinogen. Radium-228 is a beta emitter that irradiates the bone and other organs where it is deposited; EPA has classified all ionizing radiation as a group A carcinogen. Use of human epidemiology data in conjunction with the RADRISK model estimate the lifetime cancer risk from radium-228 at approximately 3×10^{-6} per pCi/l. The epidemiology studies addressing radium-226 and -228 directly also indicate that two types of cancer, bone sarcomas and head carcinomas, are elevated in persons who have been exposed to ingested radium. Rowland *et al.* (1978) compared the relative effectiveness of radium-226 and radium-228 in inducing bone sarcomas and concluded that radium-228 was more effective in inducing bone sarcomas than radium-226. In addition, they demonstrated that incidence of head carcinomas were associated only with exposure to radium-226, not radium-228. This would be expected if the accumulation of radon gas in the mastoid air cells and paranasal sinuses is important in the etiology of these tumors.

EPA also included radium-228 in its NIRS survey of ground water systems nationwide (EPA, 1988b). EPA therefore has extensive data on the occurrence of radium-228 in public water supply ground water, as described in section III. below. EPA also has data supporting the analytic chemistry methods to determine compliance with the radium-228 MCL, and treatment information showing the levels to which it can be removed from drinking water, as described in section V. below.

Finally, analytical methods for radium-226 and radium-228 differ; and, analysis of NIRS co-occurrence data suggests that in coupling regulation for the two isotopes and using the interim monitoring scheme, about half of actual violations were not detected since in most cases only a gross alpha test or radium-226 test were done (the interim monitoring requirements only required radium-228 monitoring when the gross alpha measurement exceeded 5 pCi/l, 40

CFR 141.26(a)(1)(i); EPA, 1988d). The proposed revision to the monitoring requirements described in section V. below would rectify this problem.

c. **Disposal of radioactive waste generated from treatment of water for radionuclides.** A total of 15 commenters discussed the need for EPA to address technical, regulatory, and economic aspects of treatment and disposal of radioactive waste resulting from water treatment to remove radionuclides.

Comments: Commenters urged EPA to address the issue of disposing radium-contaminated sludge from lime softening treatment, uranium-containing spent alumina, and uranium-contaminated sludge from coagulation treatment using alum or iron salts.

Commenters pointed out that the waste streams generated by reverse osmosis and electrodialysis treatments for uranium could contain triple the uranium concentration of the raw material, and that a large problem associated with reverse osmosis treatment for uranium would be disposal of large volumes of brine generated by the process and disposal of the uranium-contaminated salts remaining after brine water evaporation.

EPA Response: At the present time there are no federal regulations specifically addressing the disposal of wastes generated by water treatment processes on the basis of their radionuclide content. There are regulations that apply to disposal of radioactive wastes in general, and these would apply to drinking water treatment wastes that are radioactive.

In order to guide water treatment facilities and State and local regulators toward safe waste management practices for water treatment plant wastes containing radionuclides above background levels, EPA has reviewed regulations and guidelines which address the handling and disposal of wastes containing naturally occurring radionuclides originating from industries other than water treatment.

Based on these regulations and guidelines, EPA has developed suggested guidelines for disposal options and institutional controls which would be pertinent for drinking water treatment wastes containing naturally-occurring radioactive contaminants at various ranges of concentration. These guidelines are presented in "Suggested Guidelines for the Disposal of Drinking Water Treatment Wastes Containing Naturally-Occurring Radionuclides" (EPA, 1990a).

For disposal of liquid wastes, or brines, EPA suggests discharge to surface water, discharge to sanitary

sewer, deep well injection, or evaporation or chemical precipitation followed by land disposal, as permitted by State and local regulations. For disposal of solid wastes, or sludges, EPA suggests disposal in a municipal landfill, a stabilized or institutionally controlled landfill, a hazardous waste disposal site, a permitted or licensed naturally-occurring or accelerator-produced radioactive material (NARM) facility, or a licensed low-level radioactive waste disposal facility (should the waste become low-level radioactive waste). The selection of a waste disposal option may be influenced by a variety of federal, state or local regulatory constraints and water treatment facility site specific conditions. Waste disposal is discussed in greater detail in Section V.C below.

Comments: Eight commenters were concerned that disposal costs for water treatment waste would significantly raise the treatment costs presented in the ANPRM.

EPA Response: The treatment and disposal of wastes generated by the treatment processes could increase overall treatment costs and may be beyond affordability for some small systems. However, in establishing proposed BAT, EPA identified the treatment and disposal technologies that are reasonably available for large metropolitan regional drinking water systems (systems which serve 50,000 to 75,000 persons). In this determination, EPA evaluates total, or national compliance costs as well as household costs. EPA has determined that disposal of waste from treatment for radionuclides does not significantly increase the total water treatment costs for large systems and that the proposed regulations are, overall, affordable. EPA has also included the estimated cost of waste disposal in its overall evaluation of cost of the proposed regulations (EPA, 1991i). Estimates of waste generation and cost of disposal are described in Tables 12-14, in section V.C below.

As previously mentioned, under certain conditions, variances and exceptions from any MCL requirement or NPDWR treatment technique requirement may be available for some small systems (see section V.I). Variances and exemptions may be granted by the States to systems if installed BAT does not achieve compliance, or for compelling economic reasons, as long as granting such a variance would not result in an unreasonable risk to the health of the water supply customers.

d. *EPA's proposal to set a MCLG and MCL for gross alpha radiation.* A total of 19 individuals or organizations

submitted comments on EPA's proposal for regulating gross alpha particle activity.

Comments: A majority of the commenters responding to this issue disagreed with EPA's proposal to regulate gross alpha radiation with an MCLG and MCL; favoring the idea that gross alpha be used as a screening device only.

In support of a MCL, one commenter asserted that a total alpha activity MCL must be promulgated because Congress included "gross alpha particle activity" as one of the 83 contaminants specified for MCL development under the SDWA.

EPA Response: Compliance monitoring has only occasionally detected naturally-occurring radionuclides in drinking water other than radium-226, radium-228, uranium, or radon-222. Nevertheless, EPA believes that this does not preclude the possible presence of other alpha emitters, including transuranic man-made alpha emitters, and believes that a MCLG and MCL for gross alpha particle activity will provide adequate protection from alpha emitters that could potentially occur in drinking water. EPA believes an MCL for gross alpha particle activity will also provide a ceiling on the aggregate exposure and aggregate risk from all alpha emitting radionuclides. EPA is also obligated to develop an MCL for gross alpha emitters by the 1986 amendments to the SDWA, which listed gross alpha as one of the 83 contaminants to be regulated.

Gross alpha measurements will also be used as a screen for radium-226 and uranium compliance and may reduce monitoring costs.

e. *EPA's proposed amendment to the definition of gross beta and photon emitters.* Seven commenters provided comments on EPA's proposed definition of gross beta and photon emitters.

Comments: Three commenters stated that the definition is misleading because some naturally occurring radionuclides (e.g., potassium-40 and carbon-14) decay by beta emission.

Another commenter pointed out that some radionuclides which decay by processes other than alpha or beta decay, such as electron capture or alpha emission accompanied by photon emission, would be excluded by the proposed definition.

EPA Response: EPA is proposing to regulate approximately 200 beta and photon emitting radionuclides of which most, but not all are man-made. EPA considers an overall MCL for beta and photon emitters to be more appropriate than specific MCLs because of the low possibility of occurrence.

Radionuclides which decay by processes such as electron capture or alpha emission accompanied by photon emission would not be excluded from the definition.

f. *Comments on risk models used to determine estimated risk values.* A total of 14 commenters addressed the appropriateness of using an absolute risk model versus a relative risk model, and the appropriate application of risk values generated by the two models.

(1) Risk Model Selection

Comments: One commenter believed either a relative or absolute risk model was appropriate, but that the selection of a model should depend on the biological endpoint to be evaluated. This commenter added that the relative risk model could overestimate risk. Another commenter urged that EPA consider a quadratic dose-response risk model for radium-228 and for its risk in causing bone sarcomas. Two commenters stated that there are data to show sensitivity to radionuclide induced cancer decreases with age, and suggested that the relative risk model would be appropriate for younger age groups. One commenter stated that EPA should select the risk model with the most supporting data and address the upper range of risk estimates as generated by that model. One commenter believed that either relative or absolute risk models are acceptable because both methods yield negligible risk.

EPA Response: EPA recognizes that there has been no model developed to date which perfectly and consistently describes the carcinogenic risks associated with exposure to radiation and that all existing risk models can potentially over- or under-estimate actual risks. However, radiation risks are among the most studied and best understood, and there is a general consensus among the scientific community that for solid tumors other than bone, the relative risk model appears to most appropriately describe how carcinogenic risk develops over age and time. Leukemia and bone cancer appear to better fit a model in which risk peaks a few years after exposure and then decreases subsequently. This view is supported by a variety of sources (UNSCEAR, 1988), (NRPB, 1988), (RERF, 1987), (NAS, 1980, 1988). The risk models described in these sources use age- and organ-specific risk coefficients so that any age sensitivity to radiation induced cancer is incorporated in the models.

Comment: One commenter encouraged EPA to assume input parameters for risk assessment models

that are mean values as opposed to using conservative values.

EPA Response: In its risk assessments for radionuclide risks the Agency generally does use best estimates rather than conservative values.

g. Comments on the appropriateness of setting one dose equivalent MCL standard for all radionuclides found in drinking water.

A total of 11 commenters addressed the appropriateness of a combined MCL standard for all radionuclides found in drinking water.

Comments: Most commenters opposed establishing a combined MCL for alpha-emitting radionuclides for the following reasons: biological endpoints vary among isotopes, radionuclides differ with respect to occurrence and toxicology; one standard would mislead the public; and a combined standard would require an extensive effort to perform a dose assessment for each radionuclide.

One commenter noted that although it is conceptually valid to establish a combined MCL, its implementation would be more difficult due to higher analytical costs.

EPA Response: The Agency agrees that a combined MCL for all alpha-emitting radionuclides would not be an appropriate regulatory approach for two reasons. First, the effective dose equivalent (EDE) estimates for alpha particle emitters would be too uncertain to be the basis for risk assessment intended to support standards, because the range of alpha emissions is so short and the pharmacokinetics of alpha emitters are so complex (although the Agency believes they are reliable enough to be the basis for comparisons among the radionuclides). Second, it is known that some alpha-emitting radionuclides (i.e., uranium, radium and radon) are more widespread than others (EPA, 1985a; 1988b) and have more well-established carcinogenicity. Proposed monitoring requirements (i.e. gross-alpha screening) would serve to identify other, lesser occurring alpha-emitting radioactive contaminants in an effective and cost efficient manner.

The Agency agrees with the statement made by one commenter that implementation of a combined MCL would have higher costs due to the extent of unnecessary monitoring that might occur.

h. Comments on regulation of man-made radionuclides as a class. A total of 15 individuals or organizations commented on the appropriateness of establishing a MCLG and MCL as opposed to a health advisory for the entire class of man-made radionuclides.

Comments: A total of eight commenters felt that EPA should not establish MCLGs or MCLs for man-made radionuclides. Seven of these commenters expressed the view that EPA should not establish MCLGs or MCLs for man-made radionuclides because the presence of these contaminants in drinking water is generally the result of accidental discharges already addressed by other federal regulations. Five commenters stated their support for the establishment of non-regulatory Health Advisories for man-made radionuclides rather than MCLGs or MCLs.

In support of establishing both an MCLG and MCL for man-made radionuclides, two commenters proposed that EPA require monitoring of gross beta activity for a water system only long enough to establish that noncompliance with the MCL was unlikely. However, one of these commenters added that gross beta monitoring should be conducted if an event occurred that was expected to result in radionuclide contamination of the water supply.

Another commenter suggested that if an MCLG and an MCL are set, a cost-effective alternative to the requirements of the NPDWR for gross beta monitoring would be to drop strontium and tritium from the required analyses, except in the case of an accident causing greater than 50 pCi/l of gross beta emissions.

EPA Response: The Agency agrees that the presence of man-made radionuclide contamination in drinking water generally results from accidental discharges. EPA believes that because these contaminants are known carcinogens and one potential exposure pathway is through drinking water, setting an MCLG and MCL and requiring periodic monitoring for this class of radionuclides is appropriate, especially when a potential source of chronic contamination exists. In addition, EPA is obligated under the 1986 amendments to the SDWA to set an MCL for beta and photon emitters.

E. Other EPA Radon and Radiation Programs

EPA has developed the Radon Action Program, a primarily non-regulatory program, to reduce the health threat of indoor radon in air. Radon from soil gas is the principal source of radon in the air of homes, and EPA recommends that all homes be tested for radon. The relative risks of radon in air and water are discussed in more detail in section V.F. below.

EPA's Radon Action activities are conducted under the authority of the

Indoor Radon Abatement Act (IRAA). They include: National and state radon surveys to measure radon levels in homes and schools; the Radon Measurement Proficiency (RMP) program, which evaluates radon testing companies; the Radon Contractor Proficiency (RCP) program, which trains and evaluates radon mitigation contractors; the establishment of four regional training centers across the country; and the development of model standards for construction of new housing to prevent elevated radon in new homes.

EPA has also prepared a variety of public information materials to educate the public about radon and to encourage people to test their homes and reduce elevated radon levels. EPA's "Citizen's Guide to Radon," (EPA, 1986f) which recommends that indoor air radon levels above 4 pCi/l in homes be mitigated, is currently being updated to incorporate the latest health risk information on radon from both soil and water, as well as mitigation technology. EPA also works with the Advertising Council on a national media campaign to motivate the public to test homes and fix elevated levels. EPA also conducts public outreach activities with the American Lung Association on a variety of outreach activities in States across the country, including media events and workshops held during Radon Action Week last October.

Public information materials on radon testing and mitigation in the home can be obtained from the national radon hotline at 1-800-SOS-RADON.

There are also regulatory programs that restrict radon and other radionuclide exposures. In November of 1989 EPA issued final regulations restricting radon emissions to the air from several categories of point sources, under section 112 of the Clean Air Act. EPA also has standards for both existing and new uranium mining and mill-tailings piles.

F. Basics of Radiation

The study of radiation is a specialized scientific field and much of the public water supply industry and public affected by this regulation may have only a limited understanding of it. To help provide a better understanding of radiation and these proposed regulations, appendix A presents a discussion of the fundamental concepts of radiation, its nomenclature, and its measurement.

III. Occurrence and Exposure

There are approximately 2,000 known radioisotopes, or radionuclides. These

isotopes emit radiation as they undergo radioactive decay (alpha particles, beta particles and gamma rays or photon radiation). They can be classified generally into two categories: natural and man-made, and are also frequently categorized by their primary mode of radioactive decay, i.e., by alpha or beta or gamma emission. Most radionuclides are mixed emitters to some degree, and each has a primary mode of disintegration with some smaller percentage of the atoms present decaying by others. The natural radionuclides are largely alpha particle emitters with some beta particle activity from the progeny. The most significant natural radionuclides (as determined by their levels of occurrence in drinking water and their potential to cause adverse health effects by this exposure route) are radon-222, radium-226, radium-228, and uranium. Some other alpha emitting radionuclides have

occasionally been found in drinking water.

In setting drinking water MCLs, the agency generally sets individual contaminant standards. In this notice, EPA is proposing to set MCLs for the most prevalent radionuclide contaminants, and standards for broad categories of other much less prevalent radionuclide contaminants. Because in this notice EPA is proposing to set MCLs near the 10^{-4} estimated lifetime risk level for the contaminants regulated, concern about co-occurrence of these contaminants at the MCL levels arose (EPA, 1988a). Water supply systems having two or more of these contaminants at the MCLs could be placing their customers at total risk higher than EPA's target of 10^{-4} lifetime risk. In addition, co-occurrence of several that can be removed using the same treatment could make removals more cost-effective. Because the data examined to date are limited, EPA

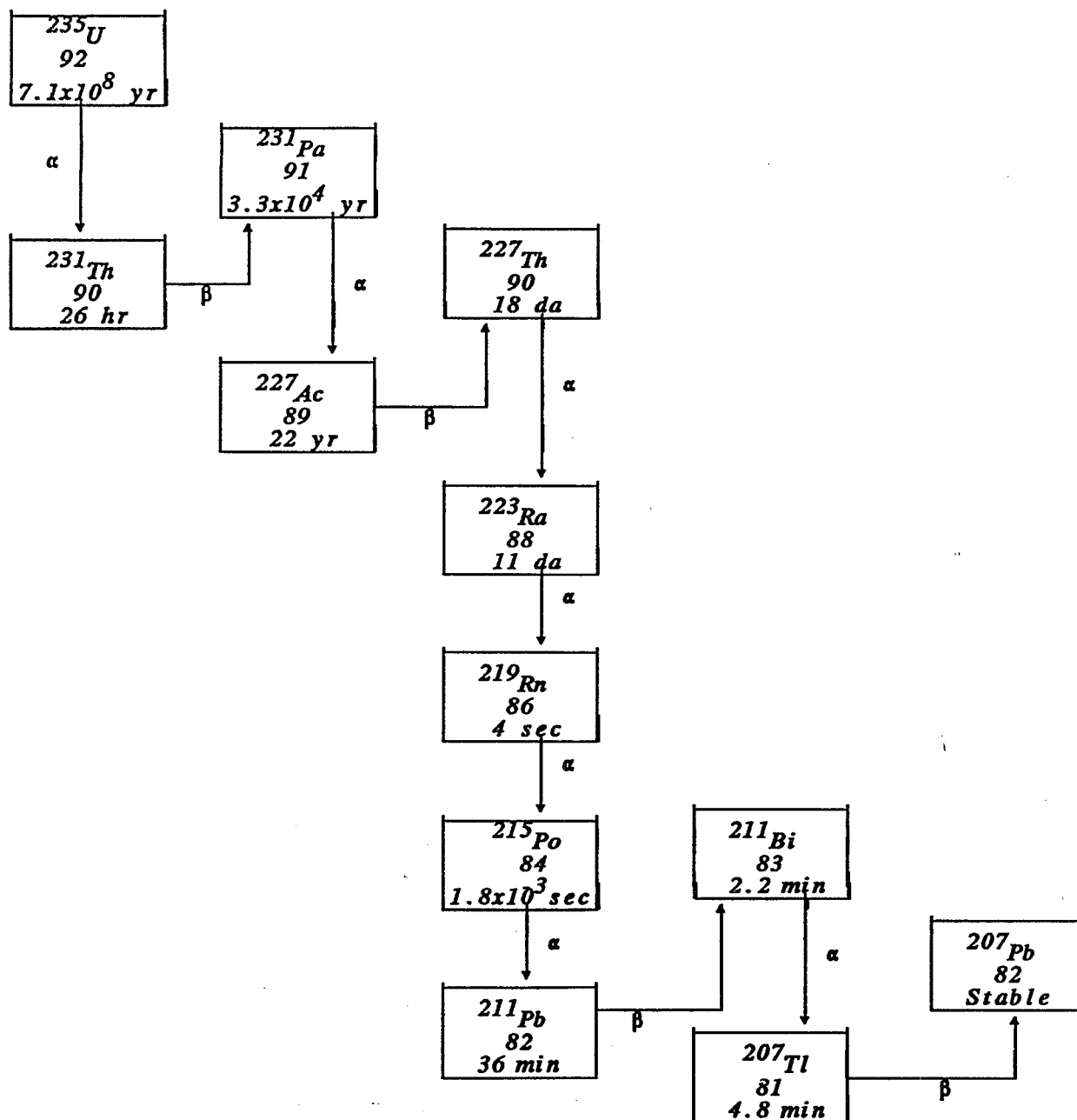
solicits additional data on co-occurrence to enable a more complete assessment of the potential for co-occurrence of these contaminants near the proposed MCLs.

The natural radionuclides involve three decay series which start with uranium-238, thorium-232 or uranium-235. These three series are shown in Figure 1. These are called the uranium, thorium, and actinium series, respectively. Each series decays through stages of various nuclides which emit either an alpha or beta particle as they decay and ends with a stable isotope of lead. A number of radionuclides also emit gamma rays, which accompany the alpha or beta decay. The uranium-238 series contains both radium-226 and radon-222 in the decay series and ends with the stable lead-206. The thorium-232 series contains radium-228 and ends with the stable lead-208.

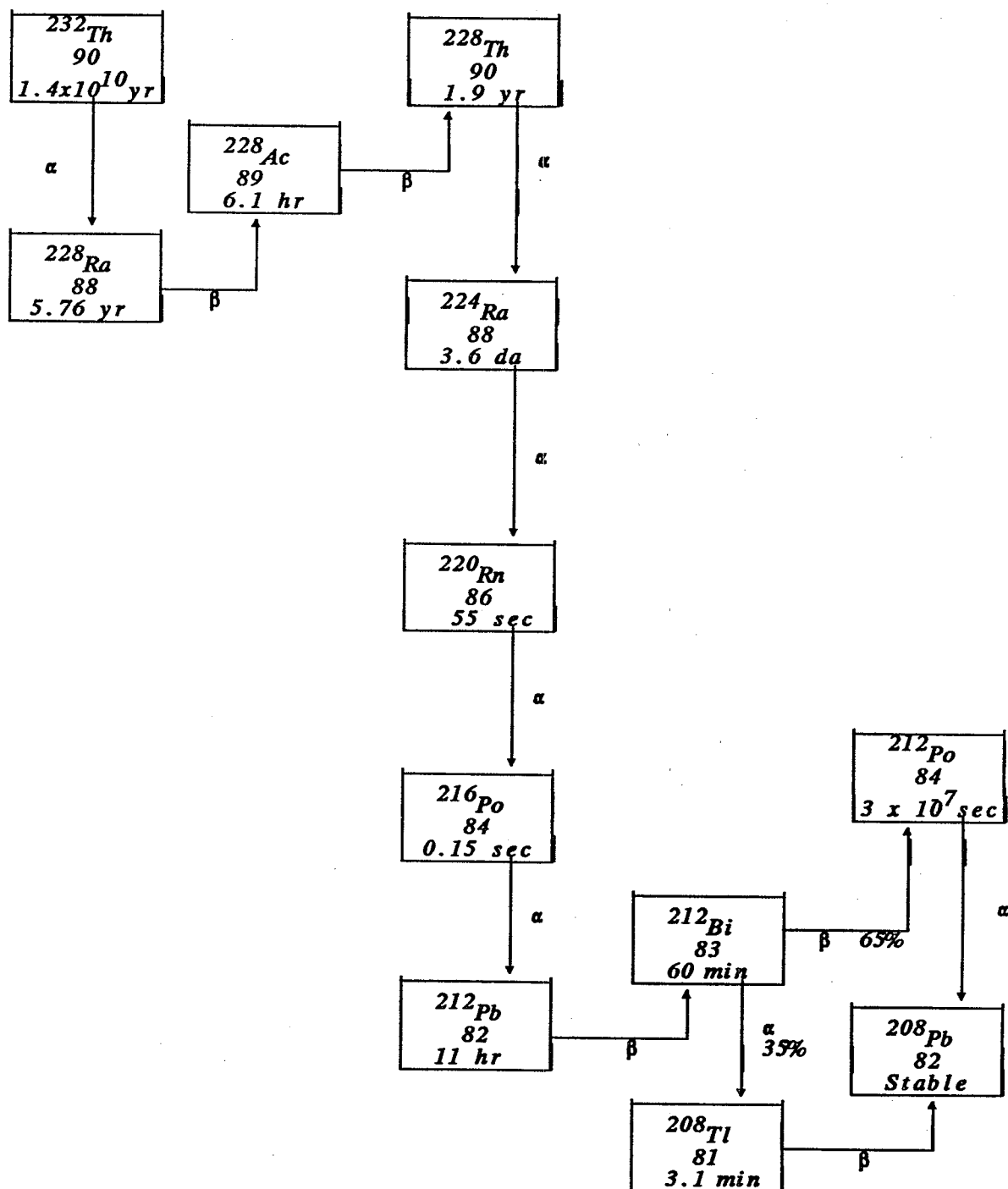
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Figure 1. Uranium and thorium isotope decay series

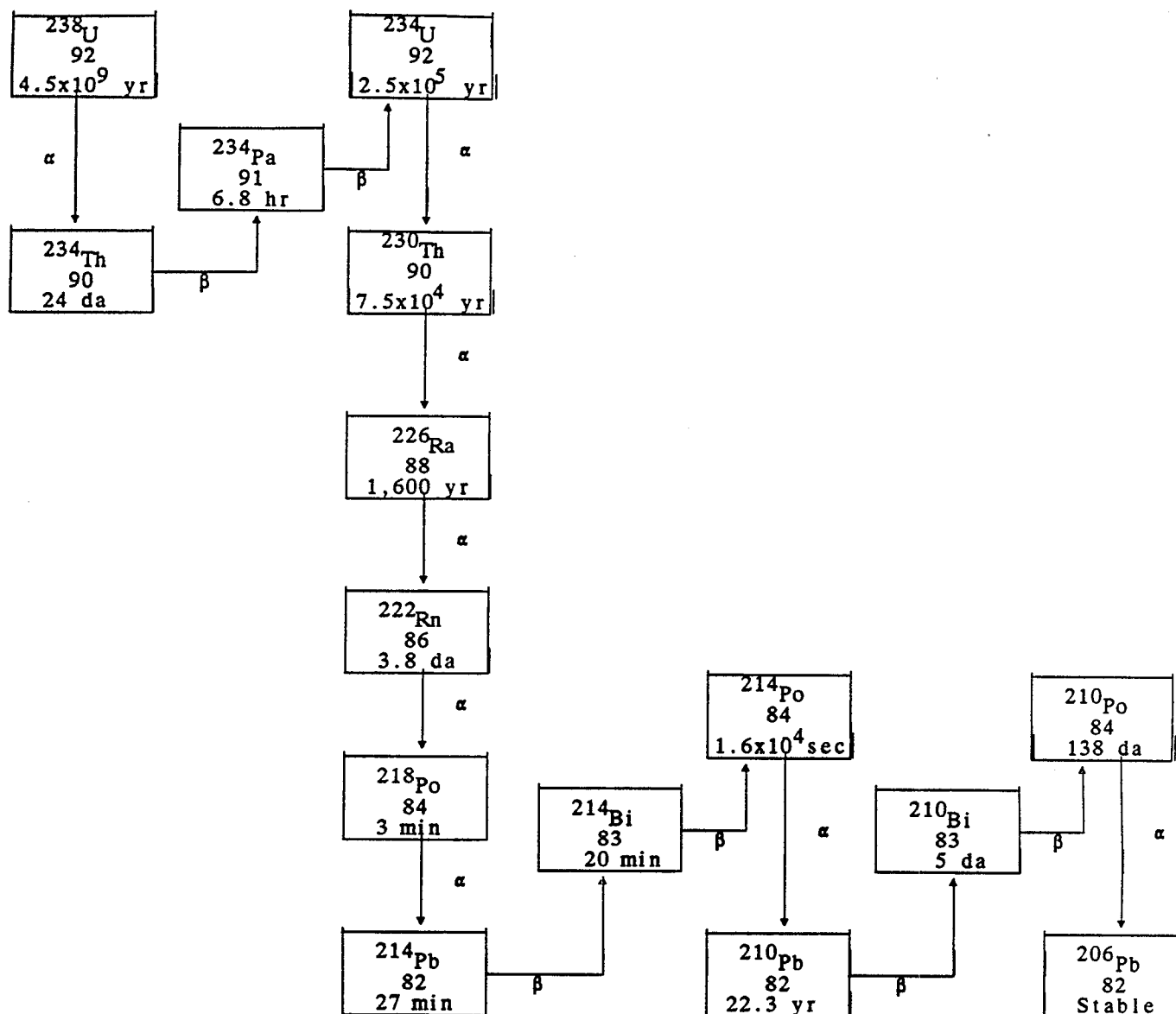
THE ACTINIUM SERIES



THE THORIUM SERIES



THE URANIUM SERIES



The man-made radionuclides fall into two subcategories. For those radionuclides of an atomic weight higher than uranium in the Periodic Table (the transuranics), generally both alpha and beta particle decay modes occur. By contrast, almost no radionuclides below thallium ($A=81$) exhibit alpha particle decay properties. They undergo decay by beta and/or gamma ray emission.

Of the radionuclides that comprise the natural decay series, radium, uranium and radon are most commonly found at detectable levels in drinking water. Many of the man-made radionuclides have half-lives too short to allow them to be transported completely through a drinking water system. (The half-life of an isotope is the time required for one-half of the atoms present to decay.) However, approximately 200 man-made radionuclides do have half-lives long enough to be considered potential contaminants in drinking water, and there are a few reported cases of high levels of naturally occurring beta emitters (e.g., lead-210) in private wells. Thus, the 200 man-made and naturally-occurring radionuclides are included as a class of beta and photon emitters in this discussion.

The estimates of radon, radium, and uranium levels in drinking water of public water systems presented in this section are based on EPA's National Inorganics and Radionuclides Survey (NIRS) (EPA, 1988b). Also presented for each radionuclide is a summary of the findings of the survey on the Nationwide Occurrence of Radon and Other Natural Radioactivity in Public Water Supplies (EPA, 1985a). The title is shortened to "The Nationwide Radon Survey" in the following discussions. NIRS was initiated in the early 1980s to characterize the occurrence of a variety of substances, including the naturally occurring radionuclides covered in this proposal. Estimations of radionuclide levels derived from other available nationwide monitoring data were presented in the Advance Notice of Proposed Rulemaking (ANPRM) (51 FR 34836, Sept. 30, 1986). These have been revised based on the NIRS data, and the impacts and benefits of this proposal are estimated based on an analysis of the NIRS data.

The NIRS (EPA, 1988b) survey was designed as a stratified sample based on the population served. The universe of public groundwater supplies was stratified into four size categories (by population): very small (serving 25–500), small (serving 501–3,300), medium (serving 3,301–10,000) and large/very large (serving more than 10,000). There are approximately 60,000 community

water systems nationwide. Of these, approximately 48,000 are served primarily by groundwater, 33,000 of which serve 500 or fewer people, about 10,000 serve people in communities of 500 to 3,300, 2,400 serve communities of 3,300 to 10,000, and about 1,200 serve 10,000 or more people. A total of 1,000 sites were selected randomly in proportion to the number of public groundwater supplies in each category. Approximately 2.1 percent of the drinking water supplies in each size category were selected. (Note: Sample results for the various constituents were reported for 990 of the 1,000 sites selected.)

The national occurrence estimates for radon, radium-226, radium-228 and uranium were obtained through statistical modeling of occurrence distributions derived from the results of NIRS. Lognormal distributions were computed for each radionuclide for each of the four size strata noted above. These distributions were computed using statistical techniques that allowed for the "non-detects" (referred to as censored data) to be taken into account in calculating the parameters of these distributions. The details of the methodology are provided in the occurrence documents prepared by EPA for these contaminants.

A. Radium-226

According to the NIRS (EPA, 1988b) data approximately 40% of the systems sampled in NIRS had radium-226 above 0.18 pCi/l, the Minimum Reporting Level (MRL). However, less than 9% of the systems exceeded 1 pCi/l and only about 1% exceeded 5 pCi/l. The maximum level reported was 15.1 pCi/l. The mean and median of the positive values (those above the MRL) were 0.87 and 0.4 pCi/l, respectively. The overall mean value was 0.4 pCi/l, assuming a value of 0.9 pCi/l (i.e., one-half the MRL) for those systems with results below the MRL.

NIRS also computed population-weighted averages for the states having supplies sampled in NIRS, and reported that the highest values were found in Illinois, Wisconsin, Minnesota, and Missouri, a region recognized by others (e.g., Hess et al., 1985) for having high radium-226 levels.

The national occurrence estimates derived from NIRS indicate that approximately 25,000 community and non-transient non-community ground water supplies in the U.S. have radium-226 level above 0.18 pCi/l. Approximately 600 of these supplies are expected to have radium-226 above 5 pCi/l (half of which serve 500 or fewer people), and approximately 70 are

expected to have levels exceeding 20 pCi/l (20 of which serve 3,300 or fewer people, and 40 of which are estimated to serve 3,300 to 25,000 people) (EPA, 1991i).

Based on those occurrence estimates, it is also estimated that 3.4 million people using ground water systems are exposed to radium-226 levels exceeding 5 pCi/l, and 890,000 are exposed to levels above 20 pCi/l (EPA, 1991i).

Quantitative estimates of radium-226 occurrence and exposure in public water supplies using surface water sources could not be generated due to the lack of comprehensive national survey data. However, based on the information discussed in Hess et al. (1985), it appears reasonable to conclude that the overwhelming majority of surface water supplies have levels between 0.1 and 0.5 pCi/l.

B. Radium-228

NIRS (EPA, 1988b) reported that radium-228 was found to exceed the MRL of 1 pCi/l in approximately 12% of the systems sampled in NIRS. Less than 4% had levels above 5 pCi/l, and the maximum value reported was 12.1 pCi/l. The mean and median of the positive values were 2.0 and 1.5 pCi/l, respectively. The overall mean, using 0.5 pCi/l for those systems below the MRL, was 0.7 pCi/l (EPA, 1990n).

The national occurrence estimates for radium-228 indicate that approximately 500 ground water supplies have levels exceeding 5 pCi/l (400 of which serve 3300 or fewer people), approximately 40 systems exceed 20 pCi/l (most serving 3300 or fewer people) and 15–20 exceed 30 pCi/l. The corresponding exposure estimates are that 1.3 million people using ground water supplies receive water with radium-228 levels above 5 pCi/l, and 164,000 are exposed to water exceeding 20 pCi/l, and about 82,000 are exposed to water exceeding 30 pCi/l (EPA, 1990n; 1991i).

Similar to radium-226, there are inadequate survey data to estimate national occurrence of radium-228 in water supplies using surface water sources. However, Hess et al. (1985) also reported that surface water levels for radium-228 are low in comparison to ground water levels.

C. Radon

1. Occurrence.

NIRS (EPA, 1988b) reported that radon was found to exceed the MRL of 100 pCi/l in approximately 72% of the supplies sampled in NIRS. About 11% of the NIRS systems were found to have levels above 1,000 pCi/l, and 1%

reported radon levels above 10,000 pCi/1. The maximum value reported was 25,700 pCi/1. The mean and median values for the positive sites were 881 and 289 pCi/1, respectively. The overall mean, using a value of 50 pCi/1 for those sites below the MRL, was reported to be 648 pCi/1.

Based on the NIRS data, it is estimated that approximately 45,000 community and non-transient noncommunity ground water supplies in the U.S. have radon levels above 100 pCi/1. About 25,900 are estimated to have levels exceeding 300 pCi/1, with 9,400 exceeding 1,000 pCi/1. Approximately 80–85% of all systems exceeding any of these values serve 500 or fewer people. It is also estimated that 47 million people are served by those systems having radon levels above 100 pCi/1, 17 million by those having radon levels above 300 pCi/1, and 2.7 million by those with levels above 1,000 pCi/1 (EPA, 1991i).

Quantitative estimates of the occurrence of radon in public water supplies using surface water sources could not be developed due to the lack of data. However, based on the limited information provided in the Nationwide Radon Survey it appears that levels in such supplies are very low compared to levels observed in ground water supplies. Of 25 surface water systems in the Nationwide Radon Survey for which data were available, 23 (92%) had levels below 100 pCi/1. The mean level was 34 pCi/1, with a maximum level reported at 240 pCi/1. The Agency requests that data on radon levels in water supplies using surface water sources in this notice be submitted, if such data are available.

Radon levels in ground water can also vary on a diurnal or longer term basis. Data on radon variability were developed by Kinner et. al (Kinner, 1990) during their study of radon treatments. A review of the monitoring data taken from several of the wells used in the treatment studies showed up to 2 fold variations in radon levels at various wells over periods of one year or less. Variability over the course of a single day was generally less than over the longer periods. EPA has also funded an ongoing study by the State of Connecticut to investigate the variability in radon levels in water. EPA will incorporate these results when they are available.

Because of this variability in radon levels in water, EPA is proposing more frequent monitoring for radon than the other contaminants proposed for regulation here, but will also allow averaging of results for determining compliance, as described in section V.G

below. EPA solicits additional data on the variability of radon levels in water, and on use of these data in establishing compliance monitoring requirements.

2. Assessing individual radon exposure from inhalation and ingestion

Because it is a volatile contaminant, radon poses exposure issues not encountered in estimating exposures (and risks) for other drinking water contaminants. In assessing exposure and risk from radon, EPA has generated two separate exposure (EPA, 1991h) and risk assessments (EPA, 1991c), by the inhalation and ingestion exposure routes.

For other volatile contaminants regulated under the SDWA, EPA has continued to use its estimate of 2 liters of daily water consumption to assess overall exposure and risk. EPA estimated that while a volatile compound may be lost from water used for cooking or to make tea or coffee (and therefore the ingestion exposure would be lost), there would be an inhalation exposure to the contaminant approximately equivalent to the amount lost in cooking, etc., via contaminant release to the air (from all water uses in the house). Because adverse health effects for the VOCs were systemic rather than route specific, exposure route was not critical if overall exposure was adequately estimated. In addition, there were few data on inhalation exposures to volatile drinking water contaminants. Therefore, continued use of the 2 liters daily water consumption served as an adequate surrogate for total exposure by both routes.

In considering exposure and risk estimation for radon there were two critical differences that led EPA to its present approach of generating two route specific exposure and risk assessments. First, it was possible to generate a reliable average estimate of inhalation exposure, although there can be substantial individual variability. Empirical studies have been conducted on the transfer of radon from water to the air of a house (Hess et. al., 1991), and several published modeling approaches to assessing exposure are available. EPA's assessment of these is described in detail in the background document "Radon in Drinking Water: Assessment of Exposure Pathways" (EPA 1991h). Second, there are important route-specific considerations in assessing radon risks. While radon is considered a known human carcinogen by both ingestion and inhalation, the type and quality of information on which to base a risk assessment is different for the two routes. Risk of lung cancer by inhalation from radon and its

progeny is based on a series of human epidemiology studies, as described below, and has many elements specific to radon with its progeny in the air. The target organ for these studies was the lung only. Risk by ingestion is based on modeled estimates of radiation dose and risk to all body organs as a result of consuming water containing radon.

In assessing indoor air exposure to radon resulting from its presence in drinking water, EPA has used an overall average estimated factor for transfer of radon from water to air of 10,000 to 1 (i.e., 10,000 pCi/l radon in water contributes 1 pCi/l to air). EPA extensively reviewed both the empirical data and the various modelling approaches that are available, including exposure to radon during showering. EPA's review is presented in "Radon in Drinking Water: Assessment of Exposure Pathways" (EPA 1991h). As described above in EPA's reply to comments from the SAB/RAC, EPA concluded that although mass balance modeling can be performed for radon from showering and other water use, assessing risk based on this information is difficult. Human activity patterns are highly variable with regard to factors that have a large influence on exposure, such as type and length of shower, flow rate, timing of multiple showers within a household, and location and use of clothes washing machines. Also, significant unanswered questions remain about the equilibrium of radon with its progeny in the shower and bathroom, the unattached fraction, and aerosol particle size in a shower and behavior of water aerosols in the respiratory tract. Modeling does allow for risks from showers to be broadly bounded, and EPA has done so in its review. EPA concluded that exposure and risk estimates developed from modeled water use throughout the house (including showering) differ only slightly from the results obtained from use of an average water to air transfer factor such as 10,000:1, based on the empirical data. EPA is therefore using the 10,000:1 transfer factor as an average for purposes of assessing national risks to radon in drinking water.

In assessing exposure and risk due to ingestion of radon in water EPA used a value less than its standard assumption of 2 liters daily water consumption. Because radon is a volatile gas, only water freshly drawn from the tap and directly consumed will have appreciable amounts of radon. Even water directly consumed after being drawn will have less radon than would be measured by carefully drawing a sample from the tap for monitoring purposes, because of

aeration and agitation of the water in the process of drawing the water and consuming it. EPA therefore applied a correction factor of 0.20 (i.e., reduced by 20%) to fresh, directly consumed tap water to account for radon loss resulting from the act of drawing and drinking the water (EPA, 1991h). EPA also reviewed the available data on water ingestion rates, and presents its analysis in the background document (EPA, 1991h). This analysis separately estimates fresh tap water intake, total tap water intake, and total fluid intake. Because only freshly drawn and directly consumed tapwater is expected to contain radon, the direct tap water intake values were considered for assessing exposure to radon via ingestion. Based on this analysis, EPA estimated an average direct tapwater intake of 0.65 liters daily, rounded to 0.7 liters. However, EPA has considered its 2 liter daily intake to be a "reasonable maximum" estimate, and believes water intake for assessing radon exposure via ingestion should be consistent with this. As noted in the analysis, Ershow and Cantor (1989) found that fresh tapwater intake was 55% of total tapwater. Using this percentage with the 2 liter assumption results in a reasonable maximum fresh tap water exposure of 1.1 liters daily. EPA has rounded this value to 1 liter of daily directly consumed tap water for assessing radon exposure via ingestion of drinking water (in addition to airborne exposures).

EPA solicits public comment on the radon exposure issues discussed here. Specifically, EPA solicits public comment on use of an average water to air transfer factor of 10,000 to 1 for inhalation exposure to radon and its progeny, and on possible alternative use of models to assess exposures, especially during possible high exposure activities such as showering, and especially focusing on dosimetry issues in this exposure scenario. EPA also specifically solicits comment on its use of 1 liter daily consumption of freshly drawn, directly consumed tap water as a reasonable maximum estimate for assessing exposure to radon via ingestion, and possible alternative use of the average value of 0.7 liters daily water intake. Finally, EPA solicits comment on the estimated 20% loss of radon from water before consumption.

D. Uranium

Natural uranium contains three isotopes: uranium-234, uranium-235 and uranium-238. The corresponding percentages of occurrence in rock for these isotopes are 0.006, 0.72 and 99.27 percent by weight, respectively. However, the percent occurrence of

these isotopes relative to each other is not constant in drinking water. Uranium-238 and uranium-234 are responsible for most of the uranium radioactivity in natural waters. The overall activity-to-mass of uranium ratio for the three natural isotopes of uranium in rock is approximately 0.68 pCi/ μ g and is frequently used to estimate the activity of total uranium measured as mass (EPA, 1988b; EPA/ORNL, 1981). The 0.68 pCi/ μ g value is based on the natural crustal abundance of isotopes. The uranium-234/uranium-238 activities ratio of one, that is inherent in this assumption, may not be appropriate for samples taken from water. The Nationwide Radon Survey (EPA, 1985a), which measured uranium as well as radon, reported a range of uranium-234 to uranium-238 activity ratios in water of 0.7 to 32 with an arithmetic mean of 4.4 and a geometric mean of 2.7. Using the uranium-234 to uranium-238 activity ratio of 2.7, an overall activity to mass ratio of 1.3 pCi/ μ g was calculated for uranium as it occurs in drinking water (EPA, 1990h; 1991o). The 1.3 factor was applied to the NIRS results to convert those data from mass (μ g/l) to activity (pCi/l) for total uranium.

Approximately 72% of the sites in NIRS had uranium levels above 0.1 pCi/l (0.08 μ g/l). Most of these (70%) had levels between 0.1 and 20 pCi/l (approximately 0.08 and 15 μ g/l). Uranium was found to exceed 30 pCi/l (20 μ g/l) in only about 1% of the systems in NIRS. The maximum value found was 115 pCi/l (88.2 μ g/l) (EPA, 1991o).

Based on an analysis of the NIRS data, national occurrence estimates for community and non-transient non-community water supplies (both ground and surface water) indicate that approximately 1500 will have levels exceeding 20 μ g/l, serving approximately 875,000 people (EPA, 1991i). Of the 1500 systems exceeding 20 μ g/l, 1460 are estimated to serve 3300 or fewer people. The available data on uranium in surface water supplies was limited. Although levels are expected to be lower than for ground water systems, unlike radium and radon they may not be insignificant. As a conservative estimate of occurrence, the ground water occurrence distributions were applied to surface water systems to derive the above estimate (EPA, 1991i; 1991o).

Uranium is a kidney toxin (as well as a carcinogen) and EPA is proposing to base the MCL on kidney toxicity, as discussed in sections IV.C.3 and V.F below, because kidney toxicity may occur at levels below the 10^{-4} cancer risk level. The MCLG is being proposed

as zero, and the relative contribution of exposure from other sources is not usually considered. However, because kidney toxicity is the limiting toxic endpoint of concern for regulation, uranium exposure from sources other than drinking water was reviewed, to derive a relative source contribution (RSC) factor, to ensure that the MCL is set at a safe level.

In determining how to consider exposures by routes other than drinking water in establishing standards, EPA first reviews all relevant exposure data on the contaminant. This typically involves reviewing dietary intake data, and assessing the relative contributions of diet and drinking water to total intake. The fraction of total intake accounted for by drinking water as a source is the relative source contribution factor for drinking water. When data are inadequate to confidently estimate this value, a default value of 20% is used. A ceiling of 80% for the relative source contribution is also used. EPA's approach to determining relative source contributions is described in more detail in the Federal Register published May 22, 1989, on pages 22069-20070.

The data available on uranium intake from various food sources are described in the occurrence document for uranium (EPA 1990h; 1991o). Those data indicate that median dietary uranium intake from food is generally low, approximately 1.3 pCi/day as an average, with a 90th percentile of approximately 5 pCi/day. However, these data represent residents of only three cities, on the east coast and west coast, with no assessment of dietary intake for residents of the midwest or west, where uranium in soil and water may be higher.

EPA is proposing to use the 20% default value as the RSC for use in calculating a uranium MCL because of the poor data base for estimating dietary exposures. EPA recognizes this may be a conservative assessment, but believes it is warranted because the available data on uranium intake via food do not include areas of the country expected to have uranium in the soil and water. Those areas may need lower water contributions to total uranium intake in order to maintain total uranium intakes low enough to ensure safety from kidney toxicity. EPA solicits public comment on use of the default value of 20% RSC for uranium. EPA is especially interested in additional data on uranium intake from food to better estimate an alternative RSC value between 20% and 80%. EPA also solicits public comment on its general approach to determining the relative source contribution factor,

including its method of calculation and 20% and 80% boundaries.

E. Beta and Photon-Emitting Radionuclides

The availability of data on the occurrence of man-made radionuclides in public water supplies is very limited. The major source of relevant information is the ERAMS (Environmental Radiation Ambient Monitoring System), the data for which are published in the quarterly ERD (Environmental Radiation Data; as reported in EPA, 1989c) reports. The ERD reports provide data on gross beta, tritium, strontium-90, and iodine-131 for 78 sites (all surface water sources) that are either major population centers or selected nuclear facility environs.

The data presented in the ERD reports for 1985 through 1987 indicate that gross beta levels ranged from 0.3 to 17.8 pCi/l, with an average across all three years of less than 3 pCi/l (EPA, 1989c). There were no instances where gross beta exceeded 50 pCi/l. Tritium levels in this period were reported to range between 0 and 2,500 pCi/l, with average values across all three years generally falling between 100 and 300 pCi/l. Strontium-90 values did not exceed 0.9 pCi/l, with typical values falling below 0.2 pCi/l. Iodine-131 levels were all below 0.4 pCi/l, with average values below 0.1 pCi/l (EPA, 1989c).

As is apparent from these data, nuclear facilities routinely release very small amounts of these materials to the environment during their normal operations. These releases are of concern only to a few drinking water supplies, i.e., those supplies downstream from nuclear facilities or using a water source that may be affected by nuclear facility releases. While normal releases pose very low risks, accidental or unscheduled releases could be of concern.

One naturally occurring beta and photon emitter potentially of concern is lead-210, the first long-lived progeny of radon-222. Lead-210 was not monitored in the NIRS survey, and data on its occurrence in drinking water supplies are limited (EPA, 1991g). However, the drinking water concentration estimated to correspond to 4 mrem ede/yr (assuming 2 liters daily intake) is 1 pCi/l, a level low enough to potentially warrant health concern, and below the PQL for the gross beta screen. As discussed in section V.G below, EPA is proposing unregulated contaminant monitoring of lead-210 in public water supplies, to better assess any risk posed and to evaluate the possible need to develop an MCL for lead 210.

F. Alpha-Emitting Radionuclides

Gross alpha is a measure of the alpha particle emissions from total non-volatile alpha emitting radionuclides. Since radium 226 and uranium are alpha emitters that are proposed to be regulated separately, the gross alpha occurrence assessment is adjusted to eliminate these radionuclides. The term "adjusted gross alpha" represents total gross alpha measurements less radium 226 and uranium contributions. EPA is proposing an "adjusted gross alpha" MCL as a means of limiting exposures to a number of other radionuclides that do not occur frequently enough to warrant a national regulation but may be present in some water supplies. These include several of the progeny of the radionuclides for which contaminant-specific standards are being proposed today. The adjusted gross alpha MCL is distinguished from the gross alpha laboratory measurement to avoid confusion.

The evaluation of the NIRS (EPA, 1988b) database for adjusted gross alpha entails the manipulation of three sets of data (i.e., gross alpha, radium 226, and uranium). Each data set has its own detection limit and inherent uncertainty, and the analysis of all three data sets together to estimate occurrence increases the overall uncertainty of the results. To create the most meaningful data set of adjusted gross alpha, the NIRS data were evaluated in terms of a reasonable worst case approximation, which represents the highest reasonable estimate of gross alpha concentrations (EPA, 1991f). An attempt to estimate the lower bound was unproductive, because when lower bound assumptions were made in evaluating the three data sets together, there were too few positive data points to model national occurrence.

Due to the lack of national data, quantitative estimates of the occurrence of adjusted gross alpha in surface water supplies could not be generated independently. As a conservative estimate, the ground water occurrence distributions were applied to surface water systems (EPA, 1991f).

Based on the upper bound approximation, 17% of the systems sampled in NIRS reported adjusted gross alpha above 2.6 pCi/l, the minimum reporting level for gross alpha. The maximum level was 94 pCi/l. The overall mean and median levels were 2.7 and 1.8 pCi/l, respectively. Fewer than 7% reported levels above 5 pCi/l, 3% reported levels above 10 pCi/l, 2% reported levels over 15 pCi/l and only 1% had levels over 20 pCi/l (EPA, 1991f).

National occurrence estimates based on the upper bound approximation for adjusted gross alpha indicate about 1200 water supplies (serving 5 million people) exceeding 5 pCi/l, 300 systems (serving 1.8 million people) exceeding 10 pCi/l, 130 systems (serving 900,000 people) exceeding 15 pCi/l and 65 systems (serving 500,000 people) exceeded 20 pCi/l (EPA, 1991f, EPA, 1991i). Approximately 90% of the systems affected at any of these levels serve 3300 or fewer persons.

EPA notes however, that this analysis has a high degree of uncertainty, due to the simultaneous assessment of the three data bases together. Also, analytic problems with the gross alpha measurements in the NIRS survey preclude a more refined analysis. EPA considers the uncertainty in this estimate to be large, and that it likely over predicts occurrence.

EPA also conducted a search of the published literature to identify reports of alpha emitting radionuclides in water (EPA, 1991f). While these data are not nationally representative, and not all were measurements made in potable water, they do provide some indication of the alpha emitters that may be found in public water supplies in some instances. The most frequently occurring alpha emitter was polonium 210, which was identified in ground water at levels up to 2500 pCi/l in one sample in Florida, and at 3100 pCi/l in one sample in a uranium rich area of New Mexico. Most measurements were below these levels, in the 1 to 10 pCi/l range. Various radioisotopes of thorium were also found in ground water, although most were at or below 1 pCi/l. The same uranium rich area of New Mexico showed some higher thorium measurements. Finally, various plutonium isotopes were found in surface waters around the country, mostly at levels below 0.01 pCi/l. These levels are most likely present as nuclear fallout from above-ground nuclear explosions.

Another source of relevant information is the ERAMS (Environmental Radiation Ambient Monitoring System), the data for which are published in the quarterly ERD (Environmental Radiation Data; as reported in EPA, 1991f) reports. The ERD reports provide data on a number of beta emitters as well as plutonium-238, -239 and -240 for 78 sites (all surface water sources) that are either major population centers or selected nuclear facility environs. Average plutonium levels were generally below 0.01 pCi/l, although values as high as 0.8 pCi/l

were reported for plutonium-238 at two sites.

IV. Proposed MCLGs for Radionuclides

A. Setting MCLGs

MCLGs are set at concentration levels at which no known or anticipated adverse health effects would occur, allowing for an adequate margin of safety. Establishment of a specific MCLG depends on the evidence of carcinogenicity from drinking water exposure or the Agency's reference dose (RfD), which is calculated for each specific contaminant.

Establishing the MCLG for a chemical is generally accomplished in one of three ways depending upon its categorization (Table 1). The starting point in EPA's analysis is the Agency's cancer classification (i.e., A, B, C, D, or E). Each chemical is analyzed for evidence of carcinogenicity via ingestion. In most cases, the Agency places Group A, B1, and B2 contaminants into Category I, Group C into Category II, and Group D and E into Category III. However, where there is additional information on cancer risks from drinking water ingestion (taking into consideration weight of evidence, pharmacokinetics and exposure) additional scrutiny is conducted which may result in placing the contaminant into a different category. Asbestos and cadmium are examples where the categorization was adjusted based on the evidence of carcinogenicity via ingestion.

EPA's policy is to set MCLGs for Category I chemicals at zero. The MCLG for Category II contaminants is generally based on the RfD/DWEL (drinking water equivalent level, as described below) with an added margin of safety to account for cancer effects or is based on a cancer risk range of 10^{-5} to 10^{-6} when non-cancer data are inadequate for deriving an RfD. Category III contaminants are based on the RfD/DWEL approach.

TABLE 1.—EPA'S THREE-CATEGORY APPROACH FOR ESTABLISHING MCLGs—Continued

Category	Evidence of carcinogenicity via ingestion	MCLG setting approach
II.....	Limited evidence considering weight of evidence, pharmacokinetics, and exposure.	RfD approach with added safety margin or 10^{-5} to 10^{-6} cancer risk range.
III.....	Inadequate or no animal evidence.	RfD approach.

The MCLG for Category I contaminants is set at zero because it is assumed, in the absence of other data, that there is no known threshold. Category I contaminants are those contaminants which EPA has determined that there is strong evidence of carcinogenicity from drinking water ingestion. If there is no additional information to consider on potential cancer risks from drinking water ingestion, chemicals classified as group A (based on sufficient human epidemiological evidence) or B carcinogens are placed in Category I.

Category II contaminants include those contaminants for which EPA has determined there is limited evidence of carcinogenicity via drinking water ingestion considering weight of evidence, pharmacokinetics, and exposure. If there is no additional information to consider on potential cancer risks from drinking water ingestion, chemicals classified by the Agency as Group C carcinogens are placed in Category II. For Category II contaminants two approaches are generally used to set the MCLGs—either (1) setting the goal based upon non-carcinogenic endpoints (the RfD) then applying an additional uncertainty (safety) factor of up to 10 or (2) setting the goal based upon a nominal lifetime cancer risk calculation in the range of 10^{-5} to 10^{-6} using a conservative calculation model. The first approach is generally used; however, the second is used when valid non-carcinogenicity data are not available and adequate experimental data are available to quantify the cancer risk. EPA is currently evaluating its approach to establishing MCLGs for Category II contaminants.

Category III contaminants include those contaminants for which there is inadequate evidence of carcinogenicity via ingestion. If there is no additional information to consider, contaminants classified as Group D or E carcinogens are placed in Category III. For these

contaminants, the MCLG is established using the RfD approach.

The cancer classification for a specific chemical and the reference dose are adopted by two different Agency groups. Decisions on cancer classifications are made by the Cancer Risk Assessment Verification Endeavor (CRAVE) group, which is composed of representatives of various EPA program offices. Decisions on EPA reference doses (using non-cancer endpoints only) are made through the Agency Reference Dose work group, also composed of representatives of various EPA program offices. Decisions by CRAVE and the RfD groups represent risk assessment decisions for the Agency and are used by the respective regulatory programs as guidance for regulatory (risk management) decisions. Decisions of these two groups are published in the Agency's Integrated Risk Information System (IRIS). This system can be accessed by the public by contacting Mike McLaughlin of DIALCOM, Inc. at 202-488-0550.

The RfD is an estimate, with an uncertainty spanning perhaps an order of magnitude, of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious health effects during a lifetime. The RfD is derived from a no- or lowest-observed-adverse-effect level (called a NOAEL or LOAEL, respectively) that has been identified from a subchronic or chronic scientific study of humans or animals. The NOAEL or LOAEL is then divided by the uncertainty factor to derive the RfD.

The use of an uncertainty factor is important in the derivation of the RfD. EPA has established certain guidelines (shown below) to determine which uncertainty factor should be used:

10—NOAEL in humans. Accounts for intra-species variability.

100—LOAEL in humans or NOAEL from animal study.

1,000—Human data not available. Extrapolation from animal studies of less than chronic exposure or from a LOAEL in animals.

1-10—Additional safety factor based on scientific judgement.

In general, an uncertainty factor is calculated to consider intra- and interspecies variations, limited or incomplete data, use of subchronic studies, significance of the adverse effect, and the pharmacokinetic factors.

From the RfD, a drinking water equivalent level (DWEL) is calculated by multiplying the RfD by an assumed adult body weight (generally 70 kg) and then dividing by an average daily water

TABLE 1.—EPA'S THREE-CATEGORY APPROACH FOR ESTABLISHING MCLGs

Category	Evidence of carcinogenicity via ingestion	MCLG setting approach
I.....	Strong evidence considering weight of evidence, pharmacokinetics, and exposure..	Zero.

consumption of 2 L per day. The DWEL assumes the total daily exposure to a substance is from drinking water exposure. The MCLG is determined by multiplying the DWEL by the percentage of the total daily exposure contributed by drinking water, called the relative source contribution. Generally, EPA assumes that the relative source contribution from drinking water is 20 percent of the total exposure, unless other exposure data for the chemical are available. The calculation below expresses the derivation of the MCLG:

$$RfD = \frac{\text{NOAEL or LOAEL}}{\text{uncertainty factor}}$$

$$= \text{mg/kg/body weight/day} \quad (1)$$

$$\text{DWEL} = \frac{RfD \times \text{body weight}}{\text{daily water consumption in L/day}}$$

$$= \text{mg/L} \quad (2)$$

$$\text{MCLG} = \text{DWEL} \times \text{drinking water contribution} \quad (3)$$

For chemicals suspected as carcinogens, the assessment for non-threshold toxicants consists of the weight of evidence of carcinogenicity in humans, using bioassays in animals and human epidemiological studies as well as information that provides indirect evidence (i.e., mutagenicity and other short-term test results). The objectives of the assessment are (1) to determine the level or strength of evidence that the substance is a human or animal carcinogen and (2) to provide an upper bound estimate of the possible risk of human exposure to the substance in drinking water. A summary of EPA's carcinogen classification scheme (51 FR 33992, September 24, 1986) is:

Group A—Human Carcinogen based on sufficient evidence from epidemiological studies.

Group B1—Probable human carcinogen based on at least limited evidence of carcinogenicity to humans.

Group B2—Probable human carcinogen based on sufficient evidence in animals and inadequate or no data in humans.

Group C—Possible human carcinogen based on limited evidence of carcinogenicity in animals in the absence of human data.

Group D—Not classifiable based on lack of data or inadequate evidence of carcinogenicity from animal data.

Group E—No evidence of carcinogenicity for humans (no evidence for carcinogenicity in at least two adequate animal tests in different species or in both epidemiological and animal studies).

B. Estimating Health Risks of Radionuclides

During the years since the publication of the National Interim Primary Drinking Water Regulations (41 FR 28404, July 9, 1976), which established MCLs for radium, gross alpha, and gross beta, a great deal of additional data and better understanding of the risks posed to human health by the radionuclides discussed in this notice have been obtained. Many of these new data are presented and discussed in the ANPRM (51 FR 34836, Sept. 30, 1986) and the health criteria documents supporting this proposal.

Several different approaches have been used in assessing the risks posed by exposure to radionuclides. These fall into two broad categories: Risk assessment based directly on the results of individual scientific studies of specific compounds (either human epidemiology studies or experimental studies on animals) for developing a risk assessment for that radionuclide, or risk assessment based on dosimetric models which integrate the results of a large number of studies on a variety of radioactive compounds and radiation exposure situations into an overall model which is then used to estimate risks for many different radionuclides. Studies used to create such models include both human epidemiology studies and animal studies, and include the results of research on subjects such as the metabolic fate of different radioisotopes, risks posed by different kinds of radiation, effects of dose rate, sensitivity of internal organs to radiation, identification of sensitive sub-populations, and other relevant subjects. The Criteria Documents developed in support of this proposed regulation present both studies which could individually be used as the basis for estimating risks, and also dosimetric models (EPA, 1991a; 1991b; 1991c; 1991d; 1991e). As described below, and in the Criteria Documents, EPA has generally used the dosimetric model approach to estimating risks to the radionuclides (except for radon lung cancer risk), and

has used specific studies to make several adjustments to the modeled estimates.

There are several examples of using individual scientific studies of specific radionuclides as the basis for risk estimation for those radionuclides. These include the radium watch dial painters studies of Rowland et al. (1978) and the risk assessment developed by Mays et al. (1985), and studies of radon exposure to uranium mine workers. They also include a series of studies of patients injected with Thorotrast, a thorium-based contrasting agent used in medical radiology, which were reviewed by the BEIR IV committee (NAS, 1988). Another approach is combined analysis of several studies or cohorts of miners exposed to radon gas, as was done by the BEIR IV committee in assessing radon lung cancer risks (NAS, 1988).

In addition, there are several community ecologic studies of exposures to radionuclides in drinking water supplies and the disease rates in these communities. However, these studies do not show consistent increases in specific tumor types across studies of the same radionuclide as do the watch dial painter studies and the underground miner studies of radon. There is considerable difficulty in controlling for confounding factors in such studies and they generally do not have the specificity or statistical power to serve as the basis for a quantitative estimation of cancer risk, although some of them do give indications of possible effects and may point to future research needs. Therefore, although reviewed in the criteria documents, these are not used to estimate risks for radionuclides in drinking water.

Because all radiation has identical health effects, dosimetric models which integrate a large body of information on radiation in general as well as individual radionuclides can apply to a large number of radionuclides. This is an advantage because information on one radionuclide can be extrapolated to estimate risks from other radionuclides for which there may be fewer data. Models can also be used to estimate radiation dose, and risk, to tissues that are at lower risk and therefore not identified as target organs in epidemiology studies. Several such models have been developed. The International Council for Radiation Protection (ICRP) is one group that has developed and made several revisions to a model for predicting and controlling

radiation doses to workers exposed to radionuclides and to provide for worker safety. EPA uses a dosimetric model that is very similar to the ICRP model in a computer program called "RADRISK" which uses the ICRP type models to estimate risk to the general population due to environmental exposures. EPA views use of dosimetric models as a means of integrating all information on the risks posed by radionuclides into a more complete evaluation of the risks, and tries to appropriately use all information in establishing the model parameters.

C. Adverse Health Effects of the Radionuclides

The radionuclides for which NPDWRs are proposed in today's Notice are all classified in Group A, known human carcinogens. For radium and radon this classification is based on direct human epidemiological evidence. In the case of uranium, the classification is based on the knowledge that uranium is deposited in the body, delivering calculable doses of ionizing radiation to the tissues. This is also true of beta, gamma, and photon emitters. Despite differences in radiation type, energy or half-life, the health effects of radiation are identical.

TABLE 2.—CLASSIFICATION OF THE CARCINOGENICITY OF RADIONUCLIDES

Isotope	Cancer group	Summary of basis
Rn-222	A	Lung cancer caused by inhalation of radon and its short-lived, radioactive decay products. Increased lung cancer mortality in numerous epidemiological studies of underground miners exposed to elevated levels of Rn-222 and its radioactive decay products. Animal studies show similar results (NAS, 1988; UNSCEAR, 1988; EPA, 1991b; 1991c).
Ra-226	A	Bone sarcomas and head carcinomas in workers occupationally exposed to radium-containing paints via ingestion. Supporting human data from studies of increased cancer incidence in patients treated with Ra-224 via injection and supporting animal evidence from studies of mice injected with Ra-226 and beagle dogs injected with Ra-226 and 228 (NAS, 1988; UNSCEAR, 1988; EPA, 1991b; 1991c).
Ra-228	A	Same as Ra-226 except head carcinomas are not believed to be associated with ingestion of Ra-228 (NAS, 1988; UNSCEAR, 1988; EPA, 1991b; 1991c).

TABLE 2.—CLASSIFICATION OF THE CARCINOGENICITY OF RADIONUCLIDES—Continued

Isotope	Cancer group	Summary of basis
Uranium	A	Emission of ionizing radiation (alpha, beta and/or gamma radiation) by U and its decay products. Although there is little direct evidence of U carcinogenicity, U is found in soft tissues and concentrates in kidney and bone. These body burdens deposit calculable amounts of ionizing radiations in tissue. These tissues are expected to respond as they would to any other ionizing radiation and be at increased risk from cancer. These conclusions are supported by the results of animal studies (Hodge, 1973; Maynard et al., 1953; NAS, 1988; EPA, 1991e).
Beta/gamma.	A	Extensive human epidemiological data in a number of irradiated populations show increasing risks of various types of cancers with increasing doses of ionizing radiation; most notably, the Japanese atomic bomb survivors. Also supported by animal study results (NAS, 1988).

1. Radium-226 and Radium-228

The Agency has placed radium-226 in Group A based upon clear evidence of carcinogenicity to humans and animals (EPA, 1991b; 1991p). Most information on human health effects of radium comes from epidemiologic studies of two groups: (1) Radium-dial painters in the early part of this century who ingested a considerable amount of radium paint (containing various proportions of radium-226 and radium-228) by sharpening the point of the paint brush with the lips and (2) patients in Europe injected with a short-lived isotope of radium, radium-224, for treatment of spinal arthritis and tuberculosis infection of the bone (NAS, 1988; EPA, 1991b). Radium-226 and radium-228 are category I contaminants.

Harmful effects of radium result from tissue damage caused by the radioactivity of radium and its daughters (ATSDR, 1990). The dosimetry of radium is controlled by its chemical and radiological properties. Because radium is chemically similar to calcium, it is sequestered in bone, so ingestion or inhalation over a short period results in long-term accumulation. The two main isotopes of radium are: radium-226, with

a half-life of 1,600 years, and radium-228, with a half-life of 5.75 years (ATSDR, 1990). The alpha, beta, and gamma radiation released by the decay of radium and their progeny cause ionization of cellular components and the subsequent death or mutation of affected cells (EPA, 1989a).

For about half of known radium dial workers, radium exposure has been calculated from measured body burdens (Rundo et al., 1986). In most cases, only radium-226 was detected, so that exposure to radium-228 is estimated from reports of the ratio of radium-228 to radium-226 in the place of employment. This ratio varied both over time and among companies (Sharpe, 1974; Stebbings et al., 1984). Total radium intake was back extrapolated using the Norris retention function (Norris et al., 1955) and based on the gastrointestinal absorption factor of 20 percent found by Maletskos et al. (1966, 1969), ingestion was assumed to be five times the intake to the blood (Mays et al., 1985).

At higher levels of exposure to radium, several non-cancer health effects occur: benign bone growths, osteoporosis, severe growth retardation, tooth breakage, kidney disease, liver disease, tissue necrosis, cataracts, anemia, immunological suppression and death (ATSDR, 1990). The most sensitive indicator of non-cancer effects is bone necrosis scored by X-ray (Keane et al., 1983). Thirty or more years after exposure, the incidence of bone necrosis in female radium dial painters with total ingestion of radium-226 or radium-228 above 50 μ Ci was significantly higher than in unexposed controls (Keane et al., 1983). However, levels of exposure from naturally-occurring radium are much lower than this threshold, and so bone necrosis and other non-cancer health effects are usually not of concern for radium in drinking water (EPA, 1991b; EPA, 1990g; EPA, 1990n).

Scientists have long recognized that exposed radium dial painters have elevated rates of two rare types of cancer, bone sarcomas (osteosarcomas, fibrosarcomas and chondrosarcomas) and carcinomas of head sinuses and mastoids (Evans et al., 1944; Sharpe, 1974). A recent quantitative analysis of the epidemiologic data (Rowland et al., 1978) found a highly significant excess of bone sarcomas and head carcinomas in a cohort of measured women first employed before 1930. The relative effectiveness of radium-226 and radium-228 in inducing bone sarcomas was estimated to be 1:2.5. The incidence of head carcinomas was associated with exposure to radium-226, but not radium-228 (Rowland et al., 1978). This is

expected if these cancers are due to accumulation of radon gas in the mastoid air cells and paranasal sinuses, because the radon daughter of radium-228, radon 220, decays to Ra-224 too quickly for substantial diffusion to air cells (NAS, 1988). In this cohort, a dose-squared relationship was the best fit of the data for radium-226 and radium-228 induction of bone sarcomas, while a linear relationship was the best fit for radium-226 induction of head carcinomas (Rowland et al., 1978). However, the shape of the dose-response curves are uncertain because radium intake is not known for about one third of the cases of bone sarcomas and head carcinomas.

Patients medically treated with radium-224, a daughter of radium-228, also show an increase in bone sarcomas, but not head carcinomas (Mays and Speiss, 1984). These data are consistent with a linear dose-response relationship (NAS, 1988). The risk coefficient for bone cancer which is used in the RADRISK model is derived from data on exposure to radium-224 (NAS, 1980; EPA, 1991b) because actual exposures to radium-226 and radium-228 to the watch dial painters is not well known, and because of the uncertainty that would be introduced in deriving a linear risk coefficient from significantly non-linear data.

No statistically significant increase in cancers other than bone sarcomas and head carcinomas have been found in cohorts of radium dial painters (Stebbings et al., 1984). Increases in breast cancer and multiple myeloma are better correlated with duration of employment, a surrogate for external dose of gamma irradiation, than with radium intake (Stebbings et al., 1984). The lack of an increase in leukemias is unexpected, because the accumulation of radium in bone would be expected to provide substantial irradiation of potentially leukemogenic cells (Mays et al., 1985), and external irradiation has clearly been established as a cause of leukemia in humans (NAS, 1980). Possible explanations for the lack of observable increase in leukemias include alterations in bone architecture, non-uniformity of irradiation, lethality of irradiation to marrow cells, low frequency of leukemogenic cells in irradiated regions, misdiagnosis of bone marrow diseases, incomplete ascertainment of the cohort, and overestimation either of the risk coefficient for beta and gamma irradiation or of the relative effectiveness of alpha irradiation (EPA, 1991b).

Possible correlations between cancer rates and radium in drinking water have been examined in three studies in the United States. Petersen et al. (1966) found an elevated rate of fatalities from bone malignancies among residents of Iowa and Illinois with elevated radium-226 in drinking water, but the statistical significance was marginal and confounding factors could not be ruled out (NAS, 1988). Bean et al. (1982) found an increased incidence of 4 out of the 10 cancers investigated among Iowa residents of small communities with elevated radium-226 content of the water supply. However, confounding by radon exposure could not be ruled out and cancer sites were different from those observed in dial painters: bladder and lung cancer for males and breast and lung cancer for females. Lyman et al. (1985) found a small but consistent excess of leukemias in Florida counties with elevated radium-226 or radium-228 in private wells, but there was no evidence of a dose-response trend. Rates of colon, lung and breast cancer and lymphoma showed no consistent excess (Lyman and Lyman, 1986).

Animal studies have shown that exposure to radium causes bone sarcoma in mice, rats and dogs and leukemia in mice (ATSDR, 1990). Evans et al. (1944) produced bone sarcomas in rats by both oral exposure for 20 days and intradermal exposure for 2 days to radium-226. Experiments at Argonne National Laboratory using large numbers of CF1 female mice injected once with radium-226 demonstrated a clear increase in bone sarcomas (Finkel et al., 1969). Studies at the University of California at Davis using beagle dogs injected with radium-226 eight times at two-week intervals demonstrated a clear dose-response trend in premature deaths and incidence of bone sarcomas (Raabe et al., 1981). In addition to bone sarcomas, other malignancies associated with radium exposure in animals are eye melanomas in beagle dogs injected with radium-226 or radium-228 (Taylor et al., 1972) and leukemias in mice injected with radium-224 (Humphreys et al., 1985; Muller et al., 1988).

Quantitative estimates of the risks of low level exposure to radium in drinking water were generated by the RADRISK model and adjusted for over-prediction of leukemias lack of separate prediction of head carcinomas by radium-226, and for under-prediction of bone dose and sarcoma risk by radium-228. The resulting risks corresponding to lifetime intake of water containing 1 pCi/l are 4.4×10^{-6} for radium 226 and 3.8×10^{-6} for radium 228 (EPA, 1991b). An

alternative approach to evaluating the risks of radium in drinking water was presented by Mays et al., (1985). These investigators derived linear risk coefficients from the dial painter epidemiologic data, which, as noted above showed a significantly non-linear response for bone sarcoma incidence. Mays et al. (1985) calculated the risks corresponding to lifetime intake of water containing 1 pCi/l radium to be 8.4×10^{-6} for radium 226 and 8.8×10^{-6} for radium 228. The adjusted risk coefficients used by the Agency in evaluating the risks of radium in drinking water are about half those calculated by Mays et al. (1985), but are considered to be better estimates because of the quantitative uncertainties in the dial painter data concerning ingested dose, cancer incidence, and particularly low dose extrapolation.

There may be several sources of uncertainty in the risk estimates. These are discussed in detail in the Criteria Document (EPA, 1991b), and are briefly summarized here. They include the use of non-linear data for bone sarcomas as one part of a linear low dose extrapolation, lack of statistically significant increases in cancers other than head carcinomas and bone sarcomas in the watch dial painters, even though predicted by the model. While there may be uncertainties in the modeled risk estimates, EPA has evaluated all the available data and believes the approach selected is likely to have fewer uncertainties than other approaches to assessing radium risks at environmental intake levels.

EPA solicits public comment on its estimation of risks from radium in drinking water. In particular, EPA solicits public comment on use of the RADRISK model to assess risks, use of a linear risk model to extrapolate to low doses, and the adjustment of estimated leukemia risks and addition of the head carcinoma risks to the risk estimate, and adjustment of the radium-228 bone sarcoma risks.

In summary, the Agency's assessment of risk of drinking-water exposure to radium is based on the following:

Radium-226

- Excess incidence of bone sarcomas and head carcinomas among humans occupationally exposed to radium-226.
- Excess incidence of bone sarcomas among laboratory animals injected with radium-226.
- A calculated mortality risk from lifetime ingestion of radium-226 in drinking water of 4.4×10^{-6} /pCi/l, assuming 2 liters consumption per day. A lifetime mortality risk of 10^{-4} would

exist at approximately 22 pCi/l radium 226 in water.

Radium-228

- Excess incidence of bone sarcomas among humans occupationally exposed to radium-228.
- Excess incidence of bone sarcomas among laboratory animals injected with radium-228.
- A calculated mortality risk from lifetime ingestion of radium-228 in drinking water of 3.8×10^{-6} pCi/l, assuming 2 liters consumption per day. A lifetime mortality risk of 10^{-4} would exist at approximately 26 pCi/l radium 228 in water.

2. Radon

EPA's primary concern in regulating radon in drinking water is risk from radon released from water to the air in residences. Inhalation is the primary exposure route of concern, lung is the target organ, and lung cancer is the endpoint of primary concern. EPA also believes that some cancer risk to internal organs is posed by ingesting water containing radon, and breathing radon gas, and has developed dosimetric models for estimating risks to internal organs from these exposures (EPA, 1991c).

The Agency has classified radon-222 as a Group A carcinogen based on sufficient evidence for a causal association between exposure to radon and lung cancer in humans (EPA, 1991c; NAS, 1988). In addition, data from studies with experimental animals also provide sufficient evidence for the carcinogenicity of radon. The fact that ionizing radiation is classified as a group A carcinogen provides the basis for considering radon to pose cancer risk when ingested and for radon gas that is inhaled, absorbed and distributed (EPA, 1991p).

a. Radon risks from inhalation.

Human epidemiologic data have been obtained from groups of underground metal-ore miners mainly in the United States (Colorado Plateau), Canada (Ontario, and Eldorado) Czechoslovakia, Sweden (Malmberget), Newfoundland and Great Britain. These studies have been reviewed by NCRP (1984a,b), NIOSH (1987), ICRP (1987), NAS (1988), DOE (1988), and EPA (1989a).

The Colorado Plateau study represents a large, clearly defined, well-traced population having individual smoking histories and exposure records and a follow-up period exceeding 20 years (as reported in EPA, 19901). As of 1982, the lung cancer deaths had increased to 255 compared with about 50 expected (Standard Mortality Ratio,

SMR=510) in a cohort of 3,366 white and 780 nonwhite male miners. The major weaknesses of this study are the great number of mines (2,500) involved (some with few radon exposure measurements), self-reported work histories, and high exposure levels.

The cohort in the Ontario study consisted of 15,094 persons who worked for 1 or more months in uranium mines during the 1954-74 period (as reported in EPA, 19901). Of those with a cumulative Working Level Month (WLM) exposure of 340 WLM or greater by 1986, 14 cases of lung cancer were observed compared with 3-4 expected (SMR=412). (One WLM of exposure is approximately equal to being exposed to radon and its progeny at 200 pCi/l in air for 170 hours, or 8 hours daily for 20 days.) This study involved low mean cumulative exposures with reasonably good working histories but limited smoking histories.

The Czechoslovakian cohort consisted of 2,433 miners who began mining uranium ore in 1948-52 and had worked at least 4 years underground (as reported in EPA, 19901). For exposures of 12 years or longer, the dose-related increase in lung cancer had been established. For exposures of less than 12 years, a nonlinear relationship existed, so that increasing dose (WLM) did not result in increased risk if exposure was less than 5.6 to 9.5 years. In the 23.5 year group exposed to the highest level of radon (716 WLM), 82 lung cancers were observed compared with 10 expected (SMR=820). Recently, a significant excess of lung cancer was observed in exposure categories below 50 WLM (Sevc et al., 1988). The mean attributable annual cancer risk after about 30 years of observation in the whole study was approximately 20 cases per year per WLM/ 10^6 persons, and in persons starting exposure after 30 years of age the risk was approximately 30 cases per year per WLM/ 10^6 persons.

The Malmberget retrospective mortality study involved a cohort of 1,415 miners who had worked underground for more than one calendar year from 1897 to 1976 (as reported in EPA, 19901). Mean exposure of these miners to radon was estimated to be 93.7 WLMs. The major source of airborne radon and radon progeny was radon dissolved in groundwater. Excess lung (50 observed vs 12.8 expected, SMR=390) and stomach (28 observed vs 15.1 expected, SMR=185) cancers were reported. The excess risk for lung cancer first become evident 20 years after the beginning of underground mining. The low exposure levels, long follow-up period, and stability of the work force are the strengths of this study.

The Eldorado Beaverlodge retrospective cohort study involved 8,487 male miners exposed during 1948 to 1980 (as reported in EPA, 19901). A dose-related increase in lung cancer was seen, although no increased risk was evident at 5 WLM or less. For lung cancer deaths occurring during the 1950-80 period, 54 were observed in the mining group versus 28.27 expected (SMR=191). For those exposed to 150 WLM or greater, 10 cases were observed versus 1.04 expected (SMR=961).

In general, the response in animals to inhaled radon daughters is qualitatively similar to that in humans. However, species response has varied with respect to tumor type and latency period. The animal studies have demonstrated that radon and radon progeny can induce lung cancer in rats and dogs (EPA, 1991c).

Several risk assessments have been conducted to quantify the risk to miners exposed to radon and radon progeny. Recent concern with exposure of the general public to radon in the home environment has prompted the NAS (1988) and the ICRP (1987) to conduct risk assessments.

The NAS (1988) assessment is commonly referred to as the BEIR IV report. The Colorado Plateau, Ontario, Malmberget and the Eldorado Beaverlodge miner cohort data set were analyzed by NAS. It was concluded that the appropriate model would involve the computation of relative risk with consideration of the change in risk with time since exposure (TSE Model). The age-specific lung cancer mortality was calculated for cumulative radiation exposure, in WLM, incurred between 5 and 15 (W_1) or ≥ 15 years (W_2) before age using the equation:

$$r(\text{age, period, dose history}) = r_0(\text{age}) [1 + 0.025\gamma(\text{age}) (W_1 + 0.5 W_2)]$$

where γ has a value of 1.2 for persons younger than 55 years, a value of 1 for persons 55 to 65 years old, and 0.4 for persons older than 65. Based on this equation, the excess lifetime lung cancer mortality for males was 5.06×10^{-4} cases/WLM of lifetime exposure, and the risk for females was 1.86×10^{-4} cases/WLM of lifetime exposure. Assuming equal numbers of males and females in the U.S. population, 253 and 93 lung cancer cases in 500,000 exposed males and 500,000 exposed females would result each year (i.e. 350 lung cancer deaths/ 10^6 person-WLM of lifetime exposure).

The ICRP (1987) employed a somewhat different approach. Only three epidemiological sets were considered (Colorado Plateau, Czechoslovakia and Ontario). These were analyzed by both absolute and

relative-risk projection models.

However, the proportional hazard model (constant relative risk) was selected for analysis of radon risk in the indoor environmental. It was assumed that the lung cancer rate is proportional to radon exposure and is proportional to the normal lung cancer rate without radon exposure.

The equation for the constant relative-risk, proportional hazard model is:

$$\lambda(t) = \lambda_0(t) [1 + \int_0^t r(t_s) R(t_s) dt_s] = \text{the mortality rate at age, } t$$

where:

$\lambda_0(t)$ = age-specific lung cancer rate at age, t

$r(t_s)$ = risk coefficient at age of

exposure, t_s

$R(t_s)$ = age-dependent exposure rate

τ = time lag (minimal latency)

A correction of 0.8 was used to account for the other carcinogens present in mines but not present in indoor buildings. Another adjustment of 0.8 was made to account for differences in dose to the bronchial epithelium for indoor as compared with miner exposure. This resulted in a risk reduction factor of 0.64. The ICRP also considered the potential for increased sensitivity of young people and assigned an increased risk factor of 3 for exposure to persons age 20 or less. Thus, the final relative-risk coefficients were 0.64%/WLM for those >20 years of age and 1.9%/WLM (3×0.64) for those <20 years of age.

Employing a 10-year lagtime and the 1980 U.S. life table and vital statistics at an exposure level of 0.001 WLM/year, ICRP calculated 610 lung cancer deaths/10⁶ WLM for males and 204 for females (i.e. a combined risk of 420 lung cancer deaths/10⁶ WLM).

The current EPA estimates for lung cancer risk from radon exposure are based on an averaging of the results of the BEIR IV and ICRP 50 analyses with slight modifications (EPA, 1989a; EPA, 1991c). The EPA has accepted the BEIR IV conclusions that the dose and risk per WLM exposure in residences and in mines are basically identical, and thus no compensation is made for age- and sex-specific tracheobronchial deposition. The ICRP 50 (1987) results have been slightly modified by deleting the risk reduction factor of 0.8 used by ICRP to compensate for differences in dose to bronchial epithelium between household residents and miners. Therefore calculations in the ICRP 50 model were made using risk coefficients of 0.8%/WLM for those >20 years and 2.4%/WLM for those <20 years of age (EPA, 1989a).

The EPA's risk estimate was adjusted for an assumed background exposure of 0.25 WLM/year; the average radon exposure rate was based on 1980 U.S.

vital statistics and Nero's radon in residence distribution estimate (Nero et al., 1986).

EPA estimated the excess lifetime risk in the general population due to constant low-level lifetime exposure, based on an average of the BEIR IV and ICRP 50 estimates and the modifications discussed above, at 550 and 190/10⁶ WLM for males and females, respectively, or a combined risk of 360 lung cancer deaths/10⁶ WLM, with an estimated range of 140 to 720 lung cancer deaths per 10⁶ WLM (EPA, 1989a).

The occupancy factor of 0.75 is based on studies by Moeller and Underhill (1976) and Oakley (1972), which estimated radiation exposure and population dose in the United States and is supported by more recent reports. An equilibrium factor of radon with its progeny of 0.50 was estimated (EPA, 1991i), and EPA estimates that 10,000 pCi/l radon in water will contribute about 1 pCi/l to the air of a house, on average (EPA, 1991h).

The risk estimates for excess lung cancer deaths due to inhalation of radon can be used in estimating the risk of radon in water (EPA, 1991c). Using the above assumptions, the risk estimate of 360 deaths/10⁶ WLM is converted to units of deaths/pCi/l water as follows:

$$\begin{aligned} \text{Risk (pCi/l}_{\text{water}}) &= \\ &= (360 \text{ deaths}/10^6 \text{ WLM}) \times (51.6 \text{ WLM/WL-yr}) \times (70 \text{ yr}) \times (0.5 \text{ WL}/100 \text{ pCi/l}_{\text{air}}) \times (10^{-4} \text{ pCi/l}_{\text{air}}/\text{pCi/l}_{\text{water}}) \times (0.75) \\ &= 4.9 \times 10^{-7} \text{ deaths/pCi/l}_{\text{water}} \end{aligned}$$

Lifetime individual risk for lung cancer of 5×10^{-7} deaths per pCi/l water was estimated for inhaled radon daughters (EPA, 1991c).

However, EPA is in the process of reviewing and revising its estimate of radon risk. This review is based on the conclusions of the recent report by the National Academy of Science entitled "Comparative Dosimetry of Radon in Mines and Homes" (NAS, 1991), on results of the National Residential Radon Survey and also on comments received by EPA on the background document supporting revisions to the Citizen's Guide to Radon. The study by NAS was funded by EPA to help reduce the uncertainties of using miner data to estimate radon risks in the home. EPA has submitted a revised risk assessment to the SAB/RAC for their review, and will revise the risks estimated here, if appropriate, when the SAB/RAC completes its review and provides EPA comments. This revised risk evaluation was discussed by the SAB/RAC at a meeting held May 20 and 21, 1991. EPA anticipates that the lung cancer risk estimate for radon by inhalation (based

on the epidemiology studies) may be reduced by as much as 30% in the final revised estimate (EPA, 1991i).

As a volatile gas, radon may also be absorbed via inhalation and distributed throughout the body, posing some risk to internal organs. The human epidemiology studies do not account for this risk. EPA estimated the risk to internal organs from inhaled radon gas, using the RADRISK model, the 0.75 occupancy factor, an estimated breathing rate of 22,000 liters daily (EPA, 1989a) and the 10,000:1 water to air transfer factor (EPA, 1991h), as 2×10^{-8} deaths per pCi/l_{water}. Details of this calculation are provided in the Health Criteria Document for radon (EPA, 1991c).

EPA has also reviewed information on the interaction of smoking and lung cancer risk from radon. The BEIR IV committee (NAS 1988) concluded that the data show a multiplicative interaction between smoking and radon exposure in causing lung cancer, not an additive interaction. In reviewing the relative risks from radon to smokers EPA (EPA 1990i; EPA 1991c) estimated risk multipliers applicable to the population average risks for different categories of smokers. The categories include non-smokers, former smokers, and current smokers of different numbers of cigarettes. For non-smokers, estimated risks from radon are about 20% of the overall average population risk; for former smokers, radon risks are about 80% of the average risk. For current smokers, estimated risks range up to about 450% of the average population risk (40+ cigarettes per day), with a smoker average of 180% of overall average population risk. Heavy smokers are therefore at considerably greater risk from radon exposure than is the general population.

b. *Radon risk via ingestion.* EPA's assessment of the risk associated with radon when ingested is less certain than the estimate of risk by the inhalation exposure route. No experimental or epidemiologic data link exposure via ingestion to increased cancer rates.

In the present assessment, EPA has estimated the risk from ingestion of radon-222 in drinking water using data on organ doses recently developed for the Agency by Crawford-Brown (1990). In developing these dose estimates, Crawford-Brown used the results of biokinetics studies carried out by Correia et al., (1987; 1988) using xenon-133, a gas that behaves similarly to radon-222. Hess and Brown (1991) have also studied retention and clearance rates of radon gas when ingested in water.

Crawford-Brown developed mathematical models of the movement and accumulation of radon-222 within the various organs of the body following ingestion. Rate constants for movement of radon-222 within the various body organs were also developed. Using these models, the concentration of radon-222 in body organs was calculated under steady-state conditions.

EPA used these dose factors, an estimated 1 liter daily intake of freshly drawn directly consumed tap water and a 20% correction for radon loss from water during the process of drawing and consuming a glass of water (discussed in Section III.C above, and EPA, 1991h), in estimating the risk from ingested radon. EPA calculated the lifetime risk from ingestion of radon-222 in drinking water to be 1.5×10^{-7} per pCi/l (EPA, 1990c; 1991c). This is about 20% of the risk estimated from inhalation of radon-222 progeny from domestic use of water.

The total estimated risk for radon in water is 6.6×10^{-7} per pCi/l. This gives an estimated 1×10^{-4} individual lifetime risk at approximately 150 pCi/l in water for all water related exposure to radon (EPA, 1991c).

EPA estimates that approximately five percent of total indoor air radon is attributable to radon from drinking water on average, for homes served by groundwater. The NIRS occurrence survey showed average radon levels in public water ground water supplies to be 650 pCi/l, with a maximum reported level of 26,000 (although many private wells are known to have higher levels; EPA, 1990f). EPA estimates that approximately 200 (75 to 400) cancer fatalities per year are attributable to radon in drinking water, 80%, or 160 of which are estimated to be due to lung cancer (EPA, 1991i). Of these, approximately 85% may involve synergism with smoking. Overall, radon in homes is estimated to account for approximately 8,000 to 40,000 lung cancer deaths annually (EPA, 1989g; 1990m). Individual risks at the 4 pCi/l indoor air action level are approximately 1-5 in 100 (EPA, 1986f).

There may be several sources of uncertainty in the radon risk estimates. These are discussed in detail in the Criteria Document (EPA, 1991c), and are briefly summarized here. They include variability in the contribution of radon in water to indoor air radon levels, differences in homes and the mine environment, and estimates in distribution and effective dose to tissue of ingested radon. While there may be uncertainties in the risk estimates, EPA has evaluated all the available data and believes the approach selected is likely

to have fewer uncertainties than other approaches to assessing radon risks.

EPA solicits public comment on its assessment of risks from radon in drinking water. In particular, EPA requests comment on its estimate of water contributions to indoor air levels of radon and exposure during showering, and its estimate of risks due to directly ingesting radon in water.

3. Uranium

Exposure to uranium (U) is of concern because of the radioactive nature of uranium and its ubiquitous occurrence in the environment, including water supplies. Kidney toxicity and carcinogenicity are the primary adverse effects of concern associated with exposure to uranium (EPA, 1991e). EPA proposes to regulate uranium at the level that will be protective of both its kidney toxicity, and its carcinogenic potential as well. Studies in both humans and animals show uranium toxicity to the kidneys. The EPA has also classified uranium in Group A as a human carcinogen (sufficient evidence of carcinogenicity in humans) based on the fact that uranium emits alpha radiation, a well-established carcinogen (which is also classified in Group A; EPA, 1991p), and uranium is an analogue of radium-226, a well-known human carcinogen in bone (EPA, 1991e).

a. *Carcinogenicity.* The carcinogenic effects of uranium have been characterized based on effects of ionizing radiation generally, the similarity of uranium to isotopes of radium and on the effects of high activity uranium. Ionizing radiation has been classified by EPA as a Group A carcinogen, and EPA considers all emitters of ionizing radiation to be carcinogenic (EPA, 1991p). Studies have also shown that uranium, like radium, accumulates primarily in bone, and that bone sarcomas may result from radium ingestion (EPA, 1991b; 1991e). The induction of bone sarcomas is regarded as a common property of both radium and uranium, which is believed to result from the alpha emissions of these nuclei as they decay. Finally, studies of enriched and high activity isotopes of uranium have shown them to be carcinogenic in animal studies.

Studies using natural uranium do not provide direct evidence of carcinogenic potential (EPA, 1991e). Malignant tumors were observed in mice following injection of uranium-232 or uranium-233 (at levels greater than $0.1 \mu\text{Ci/kg}$), but not following injection of natural uranium (Finkel, 1953), probably because radiation dose levels were about 100-fold lower than the dose at which the tumors were observed for

uranium-232 and -233 by injection. Highly enriched uranium (i.e., uranium enriched with the more radioactive isotopes) has been shown to induce bone sarcomas in rats (NAS, 1988).

Existing human epidemiology data are inadequate to assess the carcinogenicity of uranium ingested in drinking water (EPA, 1991e). However, some epidemiological data do suggest that inhalation exposure to uranium or direct exposure to uranium deposits may be carcinogenic in humans. Polednak and Wilson (as cited in Dupree et al., 1987) found nonstatistically significant increases in cancers of the digestive organs in workers exposed to airborne uranium, although confounding variables were present (EPA, 1991e). Wilkinson (1985) reported higher mortality rates from gastric cancer in New Mexico counties located over uranium deposits. However, other etiological factors (such as radon progeny and trace elements) may be involved (EPA, 1991e).

EPA estimated the carcinogenic risk associated with uranium exposure using the RADRISK dosimetric model, as described in the revised Drinking Water Criteria Document for uranium (EPA, 1991e). EPA's earlier draft of this document (EPA, 1989f) and earlier risk assessment used a gastrointestinal uptake (f_1) factor of 0.20, which is revised in the updated Criteria Document (EPA, 1990e; 1991e) to 0.05 in response to comments by the SAB/RAC. While EPA believes the 0.05 value represents a best estimate, the wide range of values reported in the literature for the uranium f_1 (from less than 0.01 to 0.30) indicate that there may be substantial uncertainty associated with the 0.05 value. The individual studies bearing on this issue are described in the updated Criteria Document (EPA, 1991e). EPA solicits public comment on the issue of the uranium f_1 value.

Using a gastrointestinal uptake (f_1) factor of 0.05, risks of fatal cancer estimated using the RADRISK model indicated that uranium in water poses cancer risk of approximately 5.9×10^{-7} per pCi/l, assuming 2 liters daily intake. Concentrations in water of 1.7 pCi/l, 17 pCi/l and 170 pCi/l correspond to lifetime mortality risks of approximately 1×10^{-6} , 1×10^{-5} and 1×10^{-4} , respectively.

b. *Non-cancer effects.* The major target organ of uranium's chemical toxicity is the kidney (Hodge, 1973; Leggett, 1989; EPA, 1991s). Based on available toxicity data, rabbits have been identified as the most sensitive species (data summarized in Table 3). In humans, symptoms of transient

albuminuria and edema of the skeletal muscle developed in several laboratory workers exposed to combined vapors of uranium hexafluoride, uranium oxyfluoride, and hydrofluoric acid

(Howland, 1949). However, vapor concentration was not measured. Some of the effects may have been attributable to the direct action of fluoride, since the workers were

exposed to a mixture of chemicals; the transient renal effects, however, may be related to the toxic action of absorbed uranium (Haven and Hodge, 1949).

TABLE 3.—A COMPARISON OF 30-DAY, 1-YEAR, AND 2-YEAR NOAELS/LOAELS FOR URANIUM TOXICITY

Species/compound	NOAEL (mg U/kg/day)			LOAEL (mg U/kg/day)		
	30-day	1-yr	2-yr	30-day	1-yr	2-yr
Rat:						
UO ₂ F ₂	19	19	19	39	39	39
UO ₂ (NO ₃) ₂	24	24	24	120	120	120
UF ₄	760	760	760	7,600	7,600	7,600
Dog:						
UO ₂ F ₂	4	8	NT	8	19	NT
Rabbit:						
UO ₂ (NO ₃) ₂	ND	NT	NT	2.8	NT	NT

NT = Not tested.

ND = Not determined.

NOAEL = no observed adverse effect level

LOAEL = lowest observed adverse effect level

Source: Maynard and Hodge (1949, as cited in U.S. EPA, 1991e).

Nephrotoxicity has been reported in rats, rabbits, and/or dogs fed various soluble uranium compounds for periods of 30 days, 1 year, or 2 years (Maynard and Hodge, 1949; Maynard et al., 1953). Treatment-related histopathological changes were observed in the kidneys of rats fed UO₂F₂, UO₂(NO₃)₂·6H₂O, and

UC14. No histopathologic changes were found in the kidneys of rats fed insoluble uranium compounds. Acute (30 day) exposure of rabbits to uranyl nitrate down to 2.8 mg/kg/day in the diet resulted in renal damage at all dose levels (Maynard and Hodge, 1949; EPA, 1991s).

Renal toxicity has also been demonstrated in rats and dogs following administration of various uranium compounds in the diet for 1 or 2 years. A summary of NOAEL and LOAEL values derived from these studies is presented in Table 4.

TABLE 4.—SUMMARY OF NOAEL AND LOAEL VALUES

Compound	NOAEL percent	LOAEL percent	Effect
Uranyl nitrate.....	0.1	0.5	Body weight depression, mild tubular necrosis of kidneys.
Uranyl fluoride.....	0.05	0.1	Body weight depression.
Uranyl nitrate.....	0.1	0.5	Body weight depression, kidney changes.
Uranyl tetrafluoride.....	2	20	Body weight depression, kidney changes.
Uranium dioxide effects.....		20	No toxic

Source: Maynard and Hodge (1949, as cited in U.S. EPA, 1991e); Maynard et al. (1953, as cited in U.S. EPA, 1991e).

The mechanism of action of uranium in renal toxicity is not fully understood (Leggett, 1989). Nephritis and changes in urine composition are the primary symptoms (EPA, 1991e). Morphologically, the most evident changes occur in the proximal convoluted tubule of the nephrons. Necrosis of the tubular lining occurs first, followed by a clogging of the tubules with cellular debris and appearance of the debris (casts) in the urine. Regeneration of tubular lining cells within 2 to 3 weeks can occur in nonfatal cases, but the cells are not normal in appearance. The mechanism of action may involve interference with sodium transport across membranes, damage to lysosomes, or destruction of functional properties in mitochondria (EPA, 1991e).

In addition to renal effects, animal studies also indicate that exposure to uranium may be associated with dermal, ocular, teratogenic/reproductive, and hepatic effects as well as lethality, at higher exposures (EPA, 1991e). Histopathological changes (distortion of centrilobular and perilobular zones) were observed in the livers of rats fed 20 mg (9.5 mg U/kg) uranyl nitrate.

Oral administration of uranium to rats and mice has resulted in embryo lethality, adverse fetal and neonatal development, increased fetal resorption, reduced fetal body weight and length, adverse functioning of the reproductive system, and increased number of dead young/litter at birth and at lactation (Paternian et al., 1989; Domingo et al., 1989a; 1989b; Maynard et al., 1953). Bandom et al. (1978) found a significant increase in the prevalence of

chromosomal aberrations in uranium miners as compared with controls.

EPA identified the LOAEL as 0.02 ppm uranyl nitrate hexahydrate in food, converted to 2.8 mg uranium/kg/day, based on the kidney toxicity in rabbits (Maynard and Hodge, 1949; See Table 3). EPA applied a 1000 fold uncertainty factor to derive an RfD of 3×10^{-3} mg/kg/day (EPA, 1991s; 1991e). EPA multiplied the RfD by 70 kg and divided by 2 liters daily water intake, to derive the DWEL of 100 µg/l. If EPA were basing the MCLG on kidney toxicity, the 20% relative source contribution would be applied as discussed above. This would result in a MCLG based on kidney toxicity 20 µg/l.

EPA is proposing to set the MCLG at zero because of uranium's carcinogenicity. However, EPA is proposing to limit the MCL because of

kidney toxicity, because of the low carcinogenic potency of uranium. EPA believes drinking water MCLs must be protective of the public against all adverse health effects.

There may be several sources of uncertainty in the uranium risk evaluation. These are discussed in detail in the Criteria Document (EPA, 1991e), and are briefly summarized here. They include in particular for the uranium cancer risk estimate the f_1 factor, as well as the lack of confirmation of uranium's carcinogenicity in the available epidemiology studies. For kidney toxicity, uncertainties in uranium exposures from other sources may lead to uncertainty. While there may be uncertainties in the assessment of uranium's adverse effects, EPA has evaluated all the available data and believes the approach selected is likely to have fewer uncertainties than other approaches to assessing uranium risks.

EPA solicits public comment on the proposed MCLG of zero for uranium, including the f_1 factor, uranium's carcinogenicity, and kidney toxicity as the limiting adverse health effect.

4. Beta Particle and Photon Emitters

"Beta and photon emitters" are a broad group of mostly man-made radionuclides which characteristically decay by beta and photon emissions, which are ionizing radiation. EPA has classified ionizing radiation as a group A carcinogen (EPA, 1991p). Accordingly, the Agency considers beta and photon emitters Group A human carcinogens.

Beta and photon emitters are radionuclides that decay primarily by electron and/or photon emissions and are usually man-made. These low energy radiation emitters (low-LET) include beta emitters (electrons or positrons), gamma emitters, and x-ray emitters. There are a large number of radionuclides of concern, and each radionuclide/element has different absorption and retention properties and decay schemes. Differences in energy of irradiation, type, and geometry of irradiation also exist.

Despite differences in radiation type, energy, or half-life, the health effects from radiation are identical (EPA, 1991d), but may occur in different target organs and at different activity levels. Nonstochastic effects occur at relatively high doses of radiation but not at doses of typical environmental exposure and regulatory interest. Radionuclides having a half-life of 1 hour or less are not considered in the group proposed for regulation, since they will decay prior to consumption of drinking water. For a stochastic effect such as cancer, the probability of the effect increases with

increasing dose, and it is assumed that a threshold does not exist. The cancers produced by radiation cover the full range of carcinomas and sarcomas. Many forms of cancer have been shown to be induced by radiation (ICRP, 1977; NAS, 1990). The epidemiological basis for risk estimates specific to irradiation have been reviewed in detail in BEIR III (NAS, 1980) and by U.S. EPA (1989a). Since the available data suggest that lowered dose rates of low-LET radiation yield a lowered cancer risk, the use of risk coefficients from A-bomb survivors (which are the result of very high dose rates) will probably not underestimate risk from low-LET radiation (EPA, 1991d).

The methodology used in risk calculations is formalized in the RADRISK computer code. The calculations assume an average lifetime of 70.7 years and a cohort of 100,000 persons (Dunning et al., 1980; Sullivan et al., 1981; EPA, 1989a; 1991d). Equivalent organ doses consider the concentration of the radionuclide, the intake of water, the absorption of the radionuclide from the gastrointestinal tract into the bloodstream, the distribution to various organs or compartments, the retention, and the radiologic decay in each organ. The absorption (characterized by f_1) and fraction deposited in the organ or compartment (f_2) are functions of the chemical form and of age. The values of f_1 and f_2 and the retention functions for each radionuclide and chemical form are taken mostly from the tabulations in ICRP Publication 30 (ICRP, 1979; 1980; 1981; Sullivan et al., (1981) and Dunning et al. (1984). Organ masses are values from ICRP Publication 23 for adults (ICRP, 1975). The model integrates the organ burden for each year of life to obtain an annual burden, which is corrected for age with a nuclide-specific S-factor. The S-factors (units of dose equivalent per Ci-day) are derived by calculating the number of decays in the organ during residence and the energy absorbed as the result of the decays. Using these parameters, the dose delivered to each organ as the result of a unit intake of each radionuclide is calculated to obtain the annual dose rate. The target organs for dose estimation specified by the RADRISK code are ovaries, testes, breast, red marrow (for leukemia), lungs, thyroid, endosteal cells, stomach, lower and upper large intestine, small intestine, kidneys, bladder, spleen, uterus, thymus, thyroid, liver, and pancreas (EPA, 1989a; 1991d).

The risk factor associated with exposure to 1 Sv (Sievert; 1 Sv=100 rems) that is adopted is $39,000/10^6$ persons (or for 1 rem, 4×10^{-4} persons;

EPA, 1989a;). This risk factor is an age-adjusted estimate for cancer resulting from low-level, whole-body, low-LET radiation. At an exposure rate of 1 mrem/year, based on the above risk factor, and a lifetime of 70.7 years, the lifetime probability (P) of a radiation-induced fatal cancer is 2.8×10^{-5} per mrem ede per year. For the purpose of setting standards, the EPA generally considers allowable values for lifetime risk to lie between 10^{-6} and 10^{-4} . A lifetime cancer risk of approximately 10^{-4} corresponds to 4 mrem ede/yr.

Appendix B lists the concentrations in pCi/l that correspond to 4 mrem ede/year for each beta emitter, assuming lifetime intake of 2 liters of water daily.

There may be several sources of uncertainty in the beta and photon emitters risk evaluation. These are discussed in detail in the Criteria Document (EPA, 1991d), and are briefly summarized here. They include uncertainty in the metabolic model, including absorption, distribution and dosimetry, and the risk coefficients used for calculating risk. While there may be uncertainties in the assessment of beta and photon emitter risks, EPA has evaluated all the available data and believes the approach selected is likely to have fewer uncertainties than other approaches to assessing risks from beta and photon emitters.

EPA solicits public comment on its approach to estimating risks from beta and photon emitters in drinking water.

5. Alpha Emitters

EPA considers all ionizing radiation to be carcinogenic, and has classified the ionizing radiation released during alpha decay as a Group A carcinogen (EPA, 1991p). Therefore, as a class, alpha emitting radionuclides are considered group A carcinogens. There are also adequate data on some individual alpha emitters to conclude that they are carcinogenic. Accordingly, the Agency has placed alpha emitting radionuclides as a class in Group A as known human carcinogens (EPA, 1991a).

Alpha emitters are primarily naturally occurring, deriving from the uranium and thorium decay series. There are a more limited number of alpha emitting radionuclides (than beta emitters) that are of potential concern in public water supplies, as only a few alpha emitters have ever been reported in the published literature to occur in water. In addition to the naturally occurring radionuclides, plutonium and americium, man-made alpha emitters, may also be of concern, although these have only been found at very low (less

than 0.1 pCi/l) concentrations in drinking water (See section III.F).

As for the beta and photon emitters, risks from ingestion of alpha emitters can be evaluated using a modelling approach, combined with radionuclide-specific epidemiology or animal studies where available. Despite differences in radiation type, energy, or half-life, the health effects from radiation are identical, although they may occur in different target organs and at different activity levels. Nonstochastic effects occur at relatively high doses of radiation but not at doses of typical environmental exposure and regulatory interest. For a stochastic effect such as cancer, the probability of the effect increases with increasing dose, and it is assumed that a threshold does not exist. The cancers produced by radiation cover the full range of carcinomas and sarcomas. Essentially every form of cancer has been shown to be induced by radiation (ICRP, 1977; NAS, 1988; 1990). The type of cancer caused depends largely on where the radionuclides localize in the body as a result of metabolism. Radionuclides that are deposited in bone frequently cause bone sarcomas. Widely distributed radionuclides may increase cancer risk for many organs (EPA, 1991a). The epidemiologic basis for risk estimates specific to irradiation have been reviewed in detail in BEIR III (NAS, 1980) and by EPA (1989a). For internally deposited alpha emitters, the BEIR IV report (NAS, 1988) reviewed available information.

Risk assessment for the alpha emitters was performed using the RADRISK model (EPA, 1991a). The criteria document for alpha emitting radionuclides describes the metabolic model as do Dunning et al. (1980); Sullivan et al. (1981); and EPA (1989a), and as described above for the beta emitters. The model estimates radiation dose to organs, the dose is used to calculate risk to the organs, and the risks to organs are summed to estimate overall risk. Levels of the alpha emitters representing 10^{-4} lifetime risk in drinking water (assuming ingestion of 2 liters daily) are presented in Appendix C.

Specific alpha emitters of interest include polonium, thorium, plutonium and possibly americium as these have been found in water. There are some human epidemiology and animal data available to help in assessing the risks posed by the individual contaminants. However, there are not complete enough data on any of them to form the basis of a risk assessment, and EPA has determined that the RADRISK modelling

approach will provide the best estimates of the hazards posed by these contaminants (EPA, 1991a).

Polonium-210 is in the uranium-238 decay series, and is the daughter of lead-210, the first long-lived daughter of radon 222. The BEIR IV (NAS 1988) report reviewed the available literature on polonium. Polonium was reported to cause lymphomas in mice, and various soft tissue tumors in rats given polonium. In addition, a number of non-neoplastic adverse effects were reported in test animals, including sclerotic changes in the blood vessels, atrophy of the seminiferous epithelium and hyperplasia of the interstitial (Leydig) cells in the testes, and other effects, but all at relatively high doses. Effects in exposed humans including hematologic changes, impairment of the liver, kidney and reproductive organs, were reported by the BEIR IV committee. The BEIR IV committee concluded that there is no direct measure of risk for most polonium isotopes based on the human data, and suggested several possible means of estimating risk. EPA, as discussed, has relied on its RADRISK model in assessing polonium risk. The model estimates that polonium at 14 pCi/l in water (assuming 2 liters daily intake) would pose an approximate lifetime cancer risk of 1×10^{-4} (EPA, 1991a). Several public water supplies and private wells have exceeded this value, although most reported polonium levels were in the range of 1 to 10 pCi/l (EPA, 1991f).

The BEIR IV committee also reviewed available information on the adverse effects of thorium. Substantially better information (than for polonium) is available for human exposure because a colloidal form of thorium dioxide (ThO_2 ; Thorotrast) was used in medical radiology as a contrast agent from the 1920's until about 1955. Patients were injected with the Thorotrast. The colloidal particles posed a radiation risk to the reticuloendothelial system in which they were ultimately sequestered after injection. Various studies of the Thorotrast patients showed clear increases in liver cancers, as well as possible increases in leukemia. However, the BEIR committee discussed the limitations of these data for assessing the risk due to other forms of thorium. Forms of thorium other than ThO_2 would have a different metabolic fate than the Thorotrast, and would affect different organs. Therefore, EPA believes a dosimetric approach, as contained in the RADRISK model, provides the best available basis for assessing risk from the various thorium isotopes. Based on the model results,

EPA estimates that the various thorium isotopes pose lifetime cancer risks of 1×10^{-4} at drinking water concentrations ranging from 50 pCi/l to approximately 125 pCi/l (EPA, 1991a). Most reported thorium occurrence in drinking water was at levels near 1 pCi/l (EPA, 1991f).

Plutonium is widely present at very low levels in the environment, largely as a result of atmospheric nuclear weapons testing from 1945 to 1963. It is also found in nuclear power reactors and could be released in the event of an accident. The BEIR IV committee reviewed available data on plutonium and other transuranics. They concluded that studies in animals clearly indicate bone, liver, and lung (by inhalation) cancers caused by plutonium exposure. However, available (and limited) human epidemiology studies have not yet shown unequivocal association between plutonium exposure and cancer at any particular anatomical location. The Committee recommended risk assessment based on analogy with other radionuclides and high LET radiation exposure risks. EPA has used its RADRISK model to assess plutonium risks. The RADRISK model estimates that lifetime cancer risks of approximately 1×10^{-4} are posed by drinking water plutonium concentrations of about 7 pCi/l for the different plutonium isotopes (EPA, 1991a). Reported plutonium levels in drinking water were less than 0.1 pCi/l (EPA, 1991f).

Estimated risks for these and other alpha emitting compounds can be found in appendix C.

There may be several sources of uncertainty in the alphas risk evaluation. These are discussed in detail in the Criteria Document (EPA, 1991a), and are briefly summarized here. They include uncertainty in the metabolic model, including absorption, distribution and dosimetry, and the risk coefficients used for calculating risk. While there may be uncertainties in the assessment of risks, EPA has evaluated all the available data and believes the approach selected is likely to have fewer uncertainties than other approaches to assessing risks from alpha emitters.

EPA solicits public comment on its assessment of risks from alpha emitting radionuclides in drinking water.

D. MCLG Determinations

For the reasons stated in the preceding sections on health effects and risks (e.g., the fact that all of these radionuclides are Group A, known human carcinogens) and based on the Agency's policy of setting MCLGs for

known or probable human carcinogens at zero, the Agency is proposing to set MCLGs of zero for radon, radium-226, radium-228, uranium, and alpha and beta particle and photon emitters.

V. Proposed Maximum Contaminant Levels

Summary of the Proposal

The SDWA directs the Agency to set an enforceable standard for a contaminant (MCL) as close to the health goal for the contaminant (MCLG) as is "feasible". Feasible is defined as the use of the "best technology, treatment techniques and other means which the Administrator finds * * * are available (taking cost into consideration)". (Section 1412(b)(5).) In determining MCLs, the Agency considers a number of factors. The Agency evaluates the availability and performance of the various technologies capable of removing the contaminants, identifying those that have the highest removal efficiencies, that are compatible with other types of water treatment processes, and that are not limited to application in a particular geographic region. As the MCL levels must be generally enforceable, EPA also considers the ability of laboratories to measure reliably for the contaminants in water. EPA derives practical quantitation levels (PQLs) which reflect the contaminant concentration that can be measured by good laboratories under normal operating conditions within specified limits of precision and accuracy.

The Agency also considers the health risk associated with the contaminant. The Agency estimates both the incidence of disease and the risk to individuals. EPA has historically set a reference risk range for carcinogens at 10^{-4} to 10^{-6} lifetime individual risk; risks within this range have been considered acceptable.

The Role of Costs in Setting MCLs

In setting MCLs, the Agency also considers a number of cost elements. In the past, EPA has generally limited consideration of economic costs under the SDWA to whether a technology is affordable for large municipal water systems. (52 FR 42225 Nov. 3, 1987; "the legislative history indicates that EPA is to base MCLs on treatment technology affordable by the largest public water systems"). However, EPA has determined that nothing in the statutory language, the legislative history or EPA's prior constructions of the statute precludes consideration of cost-effectiveness in setting MCLs under the SDWA (EPA, 1990c).

EPA's focus on affordability for large systems in the past is consistent with statements in the 1974 House Committee Report:

In determining what methods are generally available, the Administrator is directed to take costs into account. * * * It is evident that what is a reasonable cost for a large metropolitan (or regional) public water system may not be reasonable for a small system which serves relatively few users. The Committee believes, however, that the quality of the Nation's drinking water relatively few users. The Committee believes, however, that the quality of the Nation's drinking water can only be upgraded if the systems which provide water to the public are organized as to be *most cost-effective*. In general, this means larger systems are to be encouraged and smaller systems discouraged. For this reason, the Committee intends that the Administrator's determination of what methods are generally available (taking cost into account) is to be afforded by large metropolitan or regional public water systems.

H.R. Rep. No. 93-1185, *A Legislative History of the Safe Drinking Water Act*, 97th Cong. second session, pp. 549-550 (1982) (emphases supplied). Far from prohibiting cost-effective solutions to the Nation's drinking water problems, the legislative history indicates that Congress wanted to encourage cost-effectiveness, but thought that promoting consolidation of small drinking water systems into larger ones would promote cost-effective solutions in the circumstances that prevailed in 1974. EPA has concluded that in light of changing circumstances since 1974, including the large number of MCLs that have been established in the meantime under the SDWA, it is no longer appropriate to focus exclusively on large system costs in order to promote cost-effective solutions that protect human health from contaminants in the nation's drinking water.

In addition to the statements in the 1974 House Committee Report, a 1986 floor statement by Senator Durenberger might be read to suggest that consideration of large system affordability is the only permissible role for considering costs under the SDWA.¹

¹ In the floor debates on passage of the conference report for the 1986 amendments to the SDWA, Senator Durenberger stated that the amendments were "not an instruction for the administrator to conduct a cost-benefit analysis to determine the MCL. The law emphatically does not provide that the administrator will set the MCL at a level where benefits outweigh costs, nor does it require EPA to balance costs and benefits in any other way. Cost only enters into the judgment of the administrator in defining which treatment technologies are to be considered best available technologies. And availability in this instance is considered only in the context of the largest supply systems." 132 Cong. Rec. S6287 (May 21, 1986).

However, EPA believes that, in context, the 1986 Durenberger floor statement was not in fact intended to preclude consideration of cost-effectiveness, as opposed to cost-benefit analysis.² Nowhere in his floor statement does Senator Durenberger reject considerations of cost-effectiveness (as opposed to cost-benefit) in setting MCLs. On the contrary, later in the same floor statement, Senator Durenberger refers to considering cost-effectiveness with approval in the context of using granular activated carbon (GAC) technology to establish MCLs. 132 Cong. Rec. S6294. EPA believes that it would be anomalous and contrary to Congressional intent to sanction using cost-effectiveness considerations in setting MCLs using one technology (GAC), which Congress clearly intended, but to prohibit consideration of cost-effectiveness in setting MCLs using other technologies which raise very similar issues.

Similarly, neither the statutory language nor EPA's prior constructions preclude considering the cost-effectiveness of requiring additional increments of technology or contaminant control in establishing MCLs. The statute requires EPA to establish the MCL as close to the maximum contaminant level goal ("MCLG") "as is feasible." SDWA Sec. 1412(a)(4), 42 U.S.C. 300g-1(a)(4). The term "feasible" is in turn defined as:

* * * feasible with the use of the *best* technology, treatment techniques and other means which the Administrator finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are available (*taking cost into consideration*).

SDWA sec. 1412(a)(5), 42 U.S.C. 3009-1(a)(5) (emphasis supplied). The dominant emphasis in the statutory language is on achieving practical results.³ Furthermore, far from

EPA's approach to considering cost-effectiveness in this rule is consistent with the literal language of Senator Durenberger's floor statement, in that EPA is considering cost-effectiveness in the context of determining which technology should be deemed "best available technology," and these cost-effectiveness considerations apply to large as well as small systems.

² In any event, even if the Durenberger floor statement had been intended to restrict EPA's discretion to consider costs in any way other than large system affordability (which EPA does not believe that it was), legally it could not have that effect. Floor statements by individual legislators, while entitled to some weight, do not effectively restrict agency discretion to adopt statutory interpretations which are otherwise reasonable and consistent with the statute, as recent Supreme Court cases have made clear. See, e.g. *Brock v. Pierce County*, 476 U.S. 253, 263 (1986).

³ One factor indicating that Congress intended the standard-setting exercise to focus on obtaining

Continued

precluding consideration of economics in setting MCLs, EPA is specifically instructed to "tak[e] cost into consideration" in determining whether a technology is available.

EPA does not believe that Congress's instruction to take economic costs into account in determining whether technologies are available was intended to preclude consideration of economic cost-effectiveness in determining which technology, or level of technology, is "best." As a matter of the ordinary meaning of language, if two technologies or levels of control achieve comparable or nearly comparable results, but one of them is much more efficient or cost-effective than the other, the more wasteful and expensive one could hardly be said to be the "best."

This plain language interpretation of "best" available technology as permitting some weighing of economic costs is reinforced by the fact that EPA has construed "best available technology" requirements in other environmental statutes to encompass cost-effectiveness, but generally not cost-benefit considerations. For example, EPA has long interpreted "best" available control technology for purposes of the PSD program under the Clean Air Act as incorporating cost-effectiveness considerations (EPA, 1979a; unreasonable adverse economic effects of an available control technology, as demonstrated by an incremental analysis of that option relative to others, are an adequate basis to reject an alternative). EPA's interpretation of the "best" available technology requirement under the Clean Air Act as allowing consideration of cost-effectiveness has been upheld by the courts. See, e.g., *Northern Plain Resource Council v. EPA*, 645 F.2d 1349 (9th Cir. 1981) (affirming EPA's rejection of an available control option on cost-effective grounds under the "best available control technology" requirements of the PSD program under the Clean Air Act).

From the standpoint of facilitating sound environmental policy, it makes little sense to set multiple MCLs based solely on considerations of the ability of large systems to afford each individual MCL. Rather, EPA believes that the overall purposes of the Safe Drinking Water Act, assuring the overall safety of the Nation's drinking water supply, will be best effectuated by a consideration of cost-effectiveness. In addition, EPA has historically set its MCLs based on 10^{-4} to 10^{-6} lifetime risk to an exposed

individual. See for example 40 CFR part 300 (National Contingency Plan), 40 CFR part 61 (Benzene NESHAPs, 54 FR Contingency Plan), 40 CFR part 61 (Benzene NESHAPs, 54 FR 38044, September 14, 1989), and 52 FR 25700-25701, July 8, 1987 (Final VOC MCLs). If cost-effectiveness could not be considered, EPA would be required to set each individual MCL at the limits of technology that could be afforded. This does not necessarily maximize the overall health benefits to the drinking water supply as a whole. The limited resources which are "affordable" would achieve greater health benefits for people served by the drinking water supply as a whole if these resources are deployed where they can achieve the greatest health benefits in the aggregate. Indeed, in prior SDWA rules, EPA has in fact taken cost-effectiveness into account in setting MCLs for certain volatile organic chemicals, albeit without extensive discussion, 52 FR 25699 (July 8, 1987), since failure to do so would lead to absurd results.

In sum, EPA has concluded that limited consideration of cost-effectiveness in setting MCLs will further the overall goal that Congress set in the SDWA, which was to maximize the health and safety of the country's drinking water supply as a whole. Setting each individual MCL at the limits of economic affordability would, in EPA's judgment, actually impede that goal by misallocating limited resources to achieving comparatively small or nonexistent health benefits based on the order in which EPA sets MCLs, rather than where the greatest health benefits can be achieved. Therefore, EPA believes it has an obligation to maximize the overall health benefits that accrue from all its actions affecting the nation's drinking water supply. For all of these reasons, EPA believes that it is consistent with the language, legislative history, and Congress's overall purposes to interpret the SDWA to allow EPA to consider cost-effectiveness in setting the level of control which is considered feasible using the best technology.

Radionuclides MCLs

In selecting MCLs for the four radionuclides that have the greatest frequencies of occurrence in public water supplies (radon, radium 226 and 228, and uranium), the Agency considered the factors described above. The Agency was able to collectively analyze these contaminants because they have the unique characteristic that all radionuclides cause cancer by the same mechanism, i.e., delivering ionizing radiation to tissue (by either external

exposure, or internally when ingested or inhaled). These individual contaminants may be viewed as vehicles for internal delivery of that ionizing radiation to different parts of the body. Indeed, the Agency has classified ionizing radiation (as well as the individual contaminants proposed for regulation here), as a class A carcinogen. This classification applies to alpha, beta and photon, and gamma ray emitters. It is therefore possible to make comparisons of either the radioactivity in water or removed from water (in pCi or uCi), or the radiation dose delivered by each of the radionuclides in terms of "rems ede". Rems ede are a way of normalizing for different radionuclides the radiation dose to the body taking into account the effect of different types of ionizing radiation on tissue as well as the distribution of dose (largely determined by metabolic destination of the radionuclides) in the body of the ingested or inhaled radionuclide. These measures permit comparison of the overall reduction in either total radioactivity or the effective dose of ionizing radiation that can be achieved with different control level options.

These common characteristics of the radionuclides allow comparisons among radon, radium 226 and 228, and uranium in terms of overall reduction in ionizing radiation in drinking water and radiation dose delivered via drinking water by implementing different control levels, and the relative cost of such reductions. These comparisons were considered in evaluating alternative MCLs.

EPA is interested in soliciting public comment on the applicability of cost-effectiveness to other drinking water contaminants.

Radon

Radon is estimated to cause about 8,000 to 40,000 (EPA, 1989g) lung cancer deaths annually. Typical indoor radon levels (1-2 pCi/l) pose estimated lifetime lung cancer risks near 1 in 100. The most significant contributor to indoor radon is soil gas. However, volatilization of radon from drinking water during household use also increases indoor radon levels thereby contributing to increased risk of lung cancer. Direct ingestion of radon may also pose some risk of stomach and other cancers (EPA, 1991c).

EPA estimates that more than 26,000 public water systems have radon in water at levels exceeding an approximate 10^{-4} individual lifetime risk level. Because radon is significantly more prevalent in drinking water than radium 226 and radium 228 or uranium,

practical results is that EPA is adjured to set standards based on practical results obtainable in the field, rather than solely in the laboratory.

radon poses the greatest risk on a nationwide basis of any of the radionuclides found to occur in drinking water (EPA, 1991i). Accordingly, the Agency first determined the appropriate MCL for radon.

In determining what radon MCL to propose, the Agency evaluated the availability and performance of the various technologies capable of removing radon. Based on this evaluation, the Agency determined that only aeration fulfills the requirements of the SDWA as best available technology for radon removal as discussed in Section V.B.2. Based on treatability, radon could theoretically be reduced to 100 pCi/l or lower in most water supply systems.

The Agency also considered whether the ability of laboratories to measure reliably for radon in water imposes any limits on where the Agency can set the MCL. The Agency determined that the radon PQL could be established at 300 pCi/l (although other researchers variously believe the number could be either lower or higher; see Sections V.C and V.D below).

The Agency then analyzed the costs of implementing a 300 pCi/l standard. The Agency estimated that costs for large systems to achieve 300 pCi/l would be very low (\$4 per household per year). The costs for small systems, while greater (\$170 per household per year in systems serving 25 to 100 persons), were found to be affordable by the Agency. Because of the large number of water systems that would need to install treatment to reach the 300 pCi/l standard, the annual nationwide costs would be approximately \$180 million. While this is a significant cost, the Agency concluded that these costs are reasonable in view of the substantial reduction in exposure to ionizing radiation and the resulting risk reduction that would be achieved. At this level, EPA estimated that up to 8300 uCi, representing approximately 200,000 person-rem sde would be removed from drinking water each year (EPA, 1991i).

Finally, the Agency estimated the health risks at the 300 pCi/l level to be a lifetime risk of approximately 10^{-4} (i.e., 2×10^{-4}). The Agency concluded that this level would be adequately protective of public health since it is within the target risk range of approximately 10^{-4} to 10^{-6} .

Taking these factors into account, the Agency is proposing to set the MCL for radon at 300 pCi/l.

Radium and Uranium

Radium 226 and 228 and uranium are also naturally occurring contaminants.

Although they are less prevalent than radon, they are present in a significant number of water systems. The total person-rem sde and associated population risk attributable to these contaminants collectively are much lower than for radon alone, although in some communities individual risks from these contaminants exceed the target risk range. The Agency identified several technologies that are highly efficient in removing radium 226 and 228 and uranium from water. Based on this evaluation, radium 226 and 228 could each be theoretically treated to a level lower than 2 pCi/l; uranium could be theoretically treated to a level lower than 5 pCi/l (see section V.B below). The Agency also established PQLs for these three radionuclides at 5 pCi/l for each (see sections V.C and V.D below). EPA's analysis indicated that it is technologically feasible to achieve control levels of 5 pCi/l for radium 226 and 228, and uranium.

The Agency then analyzed a number of cost factors. The cost of reducing radioactivity and rem sde of delivered dose by removing radium and uranium to the technically feasible level is much greater than the cost of reducing radioactivity and rem sde by removing radon (EPA, 1991i). First, the cost of the treatments for radium and uranium on a household basis, would be approximately \$20 to \$60/year for large systems and \$700 to \$800 per year for the smallest systems. These costs are far greater than for treatment of radon which would be approximately \$4 per house per year for large systems and up to \$170 per house per year for the smallest systems. The total number of both uCi and rem sde that would be removed by controlling radon at 300 pCi/l is much greater than the number that would be removed by controlling radium and uranium at the technically feasible levels. At the 300 pCi/l proposed standard for radon, nearly 8300 uCi annually, representing approximately 200,000 person-rem sde per year would be removed from drinking water. The total annual costs for removing this radiation by treating radon is about \$180 million. In contrast, at the technically feasible levels, 150 uCi, representing 86,000 rem sde of radium and uranium would be removed annually, at a cost of nearly \$400 million. The cost of removing radiation by controlling radium and uranium is approximately 200 fold greater per uCi removed and 5 fold per rem removed greater than that for radon treatment.

The Agency concludes that the cost of reducing radioactivity and rem sde of delivered dose by removing these three contaminants to the technically feasible

level is disproportionate to the cost of reducing radioactivity and rem sde by removing radon. The Agency does not believe it would be reasonable to select MCLs that would impose such disproportionate costs.

Since it is not cost-effective to set the MCLs for radium and uranium at the technically feasible levels, EPA examined alternatives at the 10^{-4} lifetime individual risk level, which are approximately 20 pCi/l for radium 226, 20 pCi/l for radium 228 and 20 μ g/l for uranium. These levels are less costly but still assure that persons served by public water systems will not be exposed to a greater than approximately 1×10^{-4} risk. In addition, the uranium value is protective against kidney toxicity, which may occur at levels far below the 10^{-4} lifetime risk level for uranium. For drinking water contaminants, EPA has set a reference risk range for carcinogens (after regulation) at 10^{-4} to 10^{-6} excess individual risk from lifetime exposure and therefore considers an approximately 10^{-4} risk protective of public health. Based on these considerations, EPA proposes to set the MCL for radium 226 at 20 pCi/l, for radium 228 at 20 pCi/l, and uranium at 20 μ g/l.

Following is a detailed discussion of the factors considered in developing this proposal.

A. BATs and Associated Costs

Section 1412(b)(6) of the Act states that each national primary drinking water regulation which establishes an MCL shall list the technology, treatment techniques, and other means which the Administrator finds to be feasible for purposes of meeting the MCL. In order to fulfill the requirements of section 1412(b)(6), the EPA has identified best available technologies (BAT) for each radionuclide covered in this proposal.

Technologies are judged to be BAT based upon the following factors: High removal efficiency, general geographic applicability, cost, reasonable service life, compatibility with other water treatment processes, and the ability to bring all of the water in a system into compliance.

Table 5 summarizes the BATs identified by EPA for the removal of the subject drinking water contaminants, and their respective removal capabilities.

Table 6 shows theoretical technology limits of BATs. The achievable effluent concentrations are based upon maximum removal of influent levels

from the NIRS survey data and maximum demonstrated BAT removal

rates. PWSs applying these BATs will not need to design treatment systems to

achieve these estimated low effluent concentrations.

TABLE 5. BAT CONTAMINANT REMOVAL RATES ¹

Contaminant	Ion exchange	Lime softening	Aeration	Reverse osmosis	Coagulation/filtration
Radon.....			Up to 99.9%		
Radium (226 and 228).....	80-97%	75-95%		87-98%	
Uranium.....	65-99%	85-99%		98-99.4%	80-95%
Beta Emitters					
—Cs-137.....	95-99%			90-99%	
—I-131.....				90-99%	
—Sr-89.....	95-99%			90-99%	
—Mixed commercially produced radionuclides.....	² 90-99%			96-99%	

¹ Information regarding removal efficiencies, test conditions and other factors are contained in the EPA Technology and Cost documents (T&C) and cost supplements to each T&C, i.e., for uranium, radium, radon and manmade radionuclides (EPA, 1984b; 1985b; 1986b; 1986c; 1987b; 1987c; 1987d; 1988e).

² Mixed bed or two bed (anionic/cationic) exchange resins. Removal rate does not include I-131.

TABLE 6.—TECHNOLOGY LIMITS FOR RADIONUCLIDE REMOVAL

Contaminant/Technology ¹ (BAT)	Greatest percent removal	Maximum ¹ Influent (pCi/l)	Achievable effluent (pCi/l)
Radon			
Aeration..	99.9	26,000	26
Radium-226			
IE.....	97	15	0.45
LS.....	95	15	0.75
RO.....	98	15	0.30
Radium-228			
IE.....	97	12	0.36
LS.....	95	12	0.60
RO.....	98	12	0.24
Uranium			
IE.....	99	88	0.9
LS.....	99	88	0.9
RO.....	99	88	0.9
CF.....	95	88	4.4
Beta Emitters			
Two bed ion exchange	99	*	*
RO.....	99	*	*

¹ Maximum levels in groundwater sources of drinking water as reported in NRS.

Note: IE (ion exchange); LS (lime softening); RO (reverse osmosis); CF (coagulation/filtration).

Source: (EPA, 1984b; 1985b; 1986b; 1986c; 1987b 1987c; 1987d; 1988e).

The total costs for the removal of specific radionuclide contaminants, using the proposed BATs, are summarized in Table 7. Tables 8 and 9 display the total capital cost and annual operation and maintenance costs, respectively. Costs cited in Tables 7, 8 and 9 are based on treatment conditions that would require removal of fairly high levels of contamination. The assumed removal rates are as follows: 50 percent for radium; 80 percent for radon; and 60 percent for uranium. The general assumptions used to develop the treatment costs include: chemical costs, capital costs amortized over 20 years at a 10 percent interest rate, current engineering fees, contractor overhead and profit, late 1986 power and fuel costs and labor rates (EPA, 1984b; 1985b; 1986b; 1986c; 1987b; 1987c; 1987d; 1988e). Costs as evaluated here assume the existence of no residential POE water treatment such as water softening for aesthetic reasons which might incidentally reduce some pollutant levels. The prevalence of such home treatments is extremely difficult to estimate and incorporate into a national level analysis.

EPA is presently conducting a study of treatment for very small water systems. All of the small system treatments for

radionuclides, and also other contaminants, are included, and verifying treatment costs is one element of this study. EPA will make this study available to the public when it is completed. EPA solicits public comment and data on treatments that may be especially well suited to small systems and any treatment systems designed for small systems, including data on treatment efficiencies, adaptability of designs to different size systems, and cost to install and operate treatment systems designed for small public water suppliers.

Costs may vary significantly from those shown, depending on local circumstances. Costs of treatment will be less than shown on Table 8 if contaminant concentration levels encountered in the raw water are lower than those used for the calculations. However, costs of treatment will be higher if additional treatment or storage requirements need to be satisfied. The costs in Tables 7, 8 and 9 do not include those attributable to the treatment and disposal of wastes generated by water treatment plants. Waste disposal techniques and associated costs are discussed in section C, following a discussion of BATs.

TABLE 7.—TOTAL PRODUCTION COST OF CONTAMINANT REMOVAL BY BAT ¹ NOT INCLUDING WASTE BY-PRODUCT DISPOSAL COST (DOLLARS/1,000 GALLONS, LATE 1986 DOLLARS)

	Population served					
	25-100	100-500	500-1,000	1,000-3,300	3,300-10,000	> 1,000,000
Radium (50% removal):						
Ion exchange.....	2.60	1.50	0.90	0.58	0.33	0.17
Lime softening, new.....	6.40	3.00	1.30	0.67	0.54	0.16
Lime softening, modified.....	3.50	1.70	0.78	0.39	0.11	0.01
Reverse osmosis.....	5.10	4.00	2.70	2.30	1.30	0.72
Radon (80% removal):						
Packed tower aeration.....	0.94	0.50	0.26	0.15	0.07	0.05
Uranium (60 removal):						
Coagulation/filtration, modified.....	4.40	2.10	0.83	0.38	0.10	0.02
Ion exchange.....	4.10	2.70	2.00	1.70	1.10	1.00

TABLE 7.—TOTAL PRODUCTION COST OF CONTAMINANT REMOVAL BY BAT ¹ NOT INCLUDING WASTE BY-PRODUCT DISPOSAL COST (DOLLARS/1,000 GALLONS, LATE 1986 DOLLARS)—Continued

	Population served					
	25-100	100-500	500-1,000	1,000-3,300	3,300-10,000	>1,000,000
Lime softening, modified	4.20	2.10	0.93	0.47	0.20	0.03
Reverse osmosis	6.20	4.70	3.50	2.70	1.50	0.89

Notes:

¹ Technologies and cost documents, and cost supplements for radium, radon, and uranium (EPA, 1984b; 1985b; 1986b; 1986c; 1987b; 1987c; 1987d; 1988e), form the basis for costs. Costs were revised in May, 1990 to account for new system level treatment design flows adopted by EPA (EPA, 1990d).

TABLE 8.—CAPITAL COST OF CONTAMINANT REMOVAL BY BAT ⁽¹⁾

(Kilo Dollars, Late 1986 Dollars)

	Population served					
	25-100	100-500	500-1,000	1,000-3,300	3,300-10,000	>1,000,000
Radium (50% removal):						
Ion exchange	36	91	180	280	350	31,000
Lime softening, new	79	130	180	240	540	55,000
Lime softening, modified	33	74	140	200	150	400
Reverse osmosis	51	160	340	820	1,000	177,000
Radon (80% removal):						
Packed tower aeration	15	33	58	78	100	13,000
Uranium (60% removal):						
Coagulation/filtration, modified	27	55	96	130	100	480
Ion exchange	41	100	200	310	330	31,000
Lime softening, modified	43	91	160	220	300	480
Reverse osmosis	64	200	500	960	1,400	249,000

Notes:

¹ Technologies and cost documents, and cost supplements for radium, radon, and uranium (EPA, 1984b; 1985b; 1986b; 1986c; 1987b; 1987c; 1987d; 1988e), form the basis for costs. Costs were revised in May, 1990 to account for new system level treatment design flows adopted by EPA (EPA, 1990d).

TABLE 9.—OPERATION AND MAINTENANCE COST OF CONTAMINANT REMOVAL BY BAT (K\$/YEAR, LATE 1986 DOLLARS)

	Population served					
	25-100	100-500	500-1,000	1,000-3,300	3,300-10,000	>1,000,000
Radium (50% removal):						
Ion exchange	1.1	2.8	7.5	17	43	13,000
Lime softening, new	3.8	11	20	28	73	9,700
Lime softening, modified	3.2	6.4	8.2	9.5	9.1	1,100
Reverse osmosis	4.5	16	45	100	200	50,000
Radon (80% removal):						
Packed tower aeration	0.2	0.6	1.4	3.1	7.6	3,400
Uranium (60% removal):						
Coagulation/filtration, modified	5.7	12	15	16	14	1,400
Ion exchange	3.4	12	39	110	250	95,000
Lime softening, modified	3.5	7.4	10	13	16	3,200
Reverse osmosis	5.1	18	52	120	230	59,000

Notes:

¹ Technologies and cost documents, and cost supplements for radium, radon, and uranium (EPA, 1984b; 1985b; 1986b; 1986c; 1987b; 1987c; 1987d; 1988e), form the basis for costs. Costs were revised in May, 1990 to account for new system level treatment design flows adopted by EPA (EPA, 1990d).

B. Best Available Technologies (BATs)

1. *Radium-226 and radium-228.* The Agency proposes that of the technologies capable of removing radium from source water, lime softening, ion exchange and reverse osmosis fulfill the SDWA requirements as BAT for radium removal. While radium-226 and radium-228 are radiologically different, they are chemically the same. Therefore, the same BATs, with the same removal efficiencies, apply to both. All of these

technologies have demonstrated high radium removal efficiencies and have been determined to be of low cost for large public water systems. All of these technologies are currently available and have been installed in public water supplies and are compatible with other water treatment processes currently in use. The full range of technical capability and unit costs for each of the proposed BATs for radium removal is summarized in the EPA publication, "Technologies and Costs for the Removal of Radium from Potable Water

Supplies" (EPA, 1984b), and the supplementary cost document for radium (EPA, 1987d). Treatments applicable to smaller systems have also been identified (EPA, 1988g; 1988h).

a. *Lime softening.* Lime softening is capable of achieving removal efficiencies for radium of 75 to 95 percent. At optimum pH levels (between 10 and 10.6) removal efficiencies of 94 to 95 percent can be achieved. Lime softening can also be used to reduce TDS, turbidity and heavy metals as well as radium and total hardness. The

estimated cost for an existing lime softening system to be modified to remove radium ranges from \$3.50/1,000 gallons treated for systems serving from 25–100 persons to \$.01/1,000 gallons treated for systems serving more than 1,000,000 persons. However, if a new lime softening plant was built to remove radium its cost would range from \$6.40/1,000 gallons to \$0.16/1,000 gallons for the same system sizes.

For a utility planning to use or currently using lime softening technology to remove radium, waste disposal concerns deserve ample consideration. Radium-226 and radium-228 concentrations in lime softening sludge have been reported by Snoeyink et al. (EPA, 1985d) to range from about 1 to 22 pCi Ra-226/g and from 2 to 12 pCi Ra-228/g dry solids. Extended sludge drying in an impoundment may increase the dry solids content to 70 percent or greater, with a corresponding increase in sludge contaminant concentration. Backwash waters may contain radium concentrations of 6 to 50 pCi/l. (EPA, 1985d).

b. *Ion exchange.* Cation exchange systems are capable of removing from 80 to 97 percent of radium from drinking water. Estimated costs range from \$2.60/1,000 gallons treated for systems serving 25–100 persons, to \$0.17/1,000 gallons treated for systems serving over 1,000,000 persons for removal of radium from ground water. Ion exchange softening systems are adaptable for both large and small systems, and are acceptable as either a new installation or an add on to an existing facility. Sodium cation exchange resins and ion exchange equipment are readily available commercially. Finished ("softened") waters may be corrosive to distribution system materials. However, a bypass of some unsoftened water, blended with the finished water, may provide adequately protective levels of calcium carbonate, reducing the finished water corrosivity. Disposal of concentrated waste brines containing relatively high TDS and radioactivity should be given full consideration before implementing this technology.

c. *Reverse osmosis.* Reverse osmosis (RO) membranes are capable of removing between 87 to 98 percent of the radium present in source water. RO has been primarily used for removing total dissolved solids (TDS) from water in treatment of brackish and sea waters for desalination purposes. At pressures of 200 and 425 psi, RO is capable of 95 and 98 percent radium removal, respectively. At reduced pressures this process is adaptable to fresh water sources. The RO method can be used by

both large and small systems. If operated to remove 50 percent of the influent radium, costs would range from approximately \$5.10/1,000 gallons treated for systems serving 25–100 persons to \$0.72/1,000 gallons treated for systems serving over 1,000,000 persons. If removal of TDS is also a goal, then using reverse osmosis is a very cost effective solution in the removal of radium from ground waters.

RO performance is adversely effected by the presence of turbidity, iron, manganese, silica or scale producing constituents in the source water. If pretreatment is not already in place to remove these constituents, the cost to install the pretreatment facilities may be an important factor. Disposal of waste brine, the reject flow representing 20 to 50 percent of the feed (source) water, and the quantity of available feed water to accommodate this technology, would require consideration by a water system in its initial evaluation of alternative technologies for radium removal.

2. *Radon.* The Agency proposes that, of the technologies capable of removing radon from source water, only aeration fulfills the requirements of the SDWA as BAT for radon removal. Aeration has demonstrated radon removal efficiencies in excess of 99.9 percent. This technology is currently available, has been installed in public water supplies, and is compatible with other water treatment processes in different regions. The full range of technical capabilities for this proposed BAT is discussed in the EPA technologies and costs document for radon (EPA, 1987b), and summarized below.

Granular activated carbon (GAC) can also remove radon from water, and was evaluated as a potential BAT for radon. However, the long empty bed contact time required for radon removal renders it infeasible for large municipal treatment systems, and it is therefore not considered a BAT for radon.

a. *Aeration.* Aeration techniques for removal of radon from drinking water include active processes such as diffuse aeration, packed tower aeration (PTA), slat tray aeration and free fall, with or without spray aerators, and passive processes such as free-standing, open-air storage of water for reduction of radon. Radon reduction by decay (into the daughter products of radon) may also occur in storage tanks and in pipelines which distribute drinking water, reducing radon by approximately 10 to 30 percent, with 8 to 30 hour detention periods. Aeration is considered BAT for meeting the proposed radon MCL due to high removal efficiencies, its relative

simplicity as a technology, relatively low cost and ease of operation, availability, and compatibility with other treatment processes. The aeration technique that a system chooses for radon reduction will depend upon source water quality (including radon and other contaminants removed or otherwise affected by aeration), institutional or manpower constraints, site-specific design factors, and local preferences.

The costs associated with the various technological options for radon reduction, such as packed tower aeration (PTA) and diffused aeration installations, have been examined (EPA, 1987b). Ninety-nine percent reduction of radon by PTA is estimated to cost from \$1.20/1,000 gallons treated for very small systems which serve 25 to 100 persons, to \$0.07/1,000 gallons treated for systems serving 1,000,000 persons. Eighty percent reduction of radon by PTA is estimated to range from \$0.94 to \$0.05 per 1,000 gallons for the same system sizes.

The following factors influence the aeration processes and therefore affect radon removal rates:

- temperature of water and ambient air
- air to water ratio
- contact time between air and water
- available area for transfer of radon from water.

PTA provides the most efficient transfer of radon from water to air, with the ability to remove greater than 99 percent of radon from water. A supply which requires a smaller reduction of radon, for example 50 percent, could opt to install PTA and treat 50 percent of its source water and subsequently blend the treated with raw water, or it may design a shorter packed tower to achieve compliance with the MCL. Other advantages of PTA include: removal of hydrogen sulfide, carbon dioxide, and VOCs, and oxidation of iron and manganese. No pilot or full-scale packed columns have yet been constructed for removal of radon at large municipal supplies. However, field tests have been performed by EPA, documented by Kinner et al. (1989; 1990), which verify the efficacy of aeration for radon removal. Since radon acts similarly to some highly volatile organic compounds, and packed columns have been shown to be the most efficient form of aeration for VOC removal, PTA is appropriate as BAT for radon.

Diffused aeration, which may remove up to 97 percent of radon in water possesses the following advantages: the potential for modifying existing basins or storage vessels for diffused aerator

installation; no packing media costs; and reduced pumping requirements. The Radon Technology and Cost document (EPA, 1987b) summarizes the case study of a full-scale diffused aeration plant in Belstone, England which was built to remove influent radon, and provided long-term removal efficiency of 97 percent. The disadvantages of diffused aeration include the requirement for increased contact time, the impracticality of large air-to-water ratios because of air pressure drops, and overall less efficient mass transfer of radon from water. The level of contact between air and water achievable in a packed tower aerator is difficult to obtain in a diffused air system. The above-referenced Belstone, England plant treated 2.5 mgd water, with 2,800 air diffusers, each designed to supply a maximum of 0.8 cubic feet per minute, and with a 24-minute retention time, achieved an air-to-water ratio of 8 to 1 for 97 percent radon reduction. In a field test of a diffused bubble aeration system, Kinner et al. (1990) report that removals of 90 to 99 percent were achieved at air-to-water ratios of 5 to 1 and 15 to 1.

Disadvantages which have been identified by Kinner et al. (1989; 1990) are the potential for bacteria fouling and iron and manganese precipitation, which may clog or otherwise impede operations at an aeration facility (PTA or diffused bubble type). These secondary effects may occur, however they would be highly dependent on source water quality conditions.

Spray aerators direct water upward, vertically, or at an angle, in such a manner that the water is broken into small droplets (by fixed nozzles on a pipe grid) which provide large surface areas for radon migration out of the water to the air. Most of the advantages cited above for diffused aeration also apply to spray aeration. Disadvantages include the need for a large operating area and operating problems during cold weather months when the temperature is below the freezing point. Costs associated with this option (for all sizes of water treatment plants) have not been developed by EPA.

EPA has evaluated other, less technology-intensive ("low-tech"),

options which may be suitable for small water systems, and which may cost less than the above options to install and operate (Kinner et al., 1989; 1990). These options include: Open air storage, free fall with nozzle-type aerator, bubble aerators, and slat tray aerators. With 24 to 48 hours detention, open air storage may reduce radon levels by 30 to 50 percent; a free fall of 2 feet with simple nozzle attachment was found to reduce radon by 65 to 75 percent with 8 hrs detention time; and a two foot free fall into a tank equipped with garden hose (punctured) bubble aerators, supplied by a laboratory air pump, yielded 85 to 90 percent radon reduction with 8 to 12 hour detention time. The above-referenced study concluded that very effective radon reduction can be achieved by simple aeration technologies that may be easily applied in small communities.

EPA has developed cost estimates for the above mentioned alternative low-tech water treatment methods, suitable for small systems that may need partial radon removal to meet the drinking water MCL. Cost estimates for small systems installing 9-hour storage/detention, diffused aeration, spray aeration, slat tray aeration, and PTA are presented in an addendum to the EPA Radon Technology and Cost Document (EPA, 1988e).

b. Secondary effects of aeration: Estimate of risks from PTA emissions of radon. Since this notice contains a proposal to reduce radon concentrations in drinking water by setting an MCL, and the EPA is proposing aeration as BAT for meeting the MCL, the Agency undertook an evaluation of risks associated with potential air emissions of radon from water treatment facilities due to aeration of drinking water. It is logical to assume that radon, removed from drinking water and released to the atmosphere, could result in some degradation of air quality and possibly pose some incremental health risk to the general population. However, the risks due to potential human exposure to PTA emissions appear very small in comparison to the risks associated with radon in drinking water (EPA, 1988c; 1989b).

In one evaluation of risks associated with potential radon emissions from aeration of drinking water (EPA, 1988c), EPA used radon data from 20 drinking water systems in the U.S. which, according to the Nationwide Radon Survey (EPA, 1985a), contained the highest levels of radon in drinking water and affected the largest populations and/or drinking water communities. EPA estimated the potential annual emissions (in pCi radon/yr), from PTA treatment facilities, assuming 100 percent radon removal, and these were applied to appropriate dispersion models. Estimates were made for the following parameters: Air dispersion of radioactive emissions, including radon and progeny isotopes of radon decay; concentrations in the air and on the ground; amounts of radionuclides taken into the body via inhalation of air and ingestion of meat, milk, and fresh vegetables, dose rates to organs and estimates of fatal cancers to exposed persons within a 50 kilometer radius of the water treatment facilities. Estimates of individual risk and numbers of annual cancer cases were completed for each of the 20 water systems, as well as a crude estimate of U.S. risks (total national risks) based on a projection of results obtained for the 20 water systems. These estimates were based on exposure analyses on a limited number of model plants, located in urban, suburban and rural settings, which were scaled to evaluate a number of facilities. (A similar approach has been used by the Agency in assessing risks associated with dispersion of coal and oil combustion products.)

The risk assessment results for the 20 systems indicate the following: A highest maximum lifetime risk to individuals at one system of 4×10^{-5} , with a maximum incidence at the same location of 0.0060 cancer cases per year; an estimate of annual cancer cases for all 20 systems of 0.016/yr; and a crude U.S. estimate of 0.4 cancer cases/year due to air emissions at all drinking water supplies to meet a hypothetical MCL of 200 pCi/l. The results of the risk assessment for potential radon emissions from drinking water facilities are given in Table 10.

TABLE 10.—ESTIMATES OF RISKS AT 20 SITES DUE TO POTENTIAL RADON EMISSIONS FROM PTA UNITS AND CRUDE ESTIMATE OF U.S. RISK¹

Scenario	Concentration in water (pCi Rn/l)	Emission from PTA (Ci Rn/yr)	Maximum life, individual risk	Cancer cases/year
20 Facilities:				
1	1,839	2.79	6×10^{-7}	.0003

TABLE 10.—ESTIMATES OF RISKS AT 20 SITES DUE TO POTENTIAL RADON EMISSIONS FROM PTA UNITS AND CRUDE ESTIMATE OF U.S. RISK¹—Continued

Scenario	Concentration in water (pCi Rn/l)	Emission from PTA (Ci Rn/yr)	Maximum life, individual risk	Cancer cases/year
2.....	5,003	6.22	1×10^{-6}	.0008
3.....	2,175	2.85	6×10^{-7}	.0004
4.....	1,890	20.89	1×10^{-5}	.0004
5.....	1,310	1.81	9×10^{-7}	.0000
6.....	1,329	91.80	2×10^{-5}	.0040
7.....	4,085	2.26	5×10^{-7}	.0001
8.....	10,640	1.18	2×10^{-7}	.0000
9.....	3,083	0.55	1×10^{-7}	.0000
10.....	3,270	9.04	4×10^{-5}	.0060
11.....	2,565	3.54	1×10^{-5}	.0023
12.....	4,092	1.75	3×10^{-7}	.0001
13.....	16,135	2.23	4×10^{-7}	.0001
14.....	3,882	0.27	1×10^{-7}	.0000
15.....	1,244	1.03	5×10^{-7}	.0001
16.....	2,437	1.35	7×10^{-7}	.0000
17.....	996	8.94	2×10^{-6}	.0008
18.....	7,890	0.87	4×10^{-7}	.0000
19.....	9,195	1.02	5×10^{-7}	.0000
20.....	7,500	1.04	5×10^{-7}	.0000
All 20 facilities.....	—	161	4×10^{-5}	.016
All U.S. drinking water plants.....	<200	4,200	—	.4
	<500	2,000	—	.2
	<1,000	900	—	.09

¹ Estimates of risk assessed using AIRDOSE-EPA, RADRISK and DARTAB air dispersion and lifetime risk computer codes (EPA, 1988c).

Numerous assumptions were applied in conducting the above analysis, including the following:

- PTA treatment applied, removing 100 percent of radon;
- typical (not site-specific) meteorology is used at the model plants, and flat terrain is assumed;
- 1980 census data were used, with people located in "population centroids" representative of census districts;
- 70-year residency at same location, and exposure to air and radon emissions persists throughout 70 yrs.;
- additive impact of exposure to emissions from more than one plant emitting radon was not accounted for.

To further investigate potential health risks due to PTA radon emissions, EPA used the MINEDOSE model developed to determine compliance of radon point sources regulated under EPA's NESHAPS standards (EPA, 1989b). In that study, worst case scenarios representing systems with radon levels ranging from 1,330 to 110,000 pCi/l were identified and their potential emissions modeled. These systems represent what may be the greatest potential among PWSs to increase risks via air emissions. Only systems with very high flow rates posed any potential for increasing ambient air radon exposure appreciably. The one modeling run that did indicate a potential problem assumed that all radon emissions came from a single point source (i.e., the entire production flow was treated through a single aeration tower). However, the

community modelled relies on numerous widely dispersed wells for its total water supply, and aeration treatment could be installed at individual wells, thereby dispersing the emissions to the ambient outdoor air. This modeling also found that systems having very high radon levels, (100,000 pCi/l) but lower flow rates, did not appreciably increase ambient air radon levels and risks.

Given the uncertainties in calculating such risk estimates, EPA views the above estimates as "order of magnitude estimates." Nevertheless, it is apparent that the risks to the U.S. population, and to the individual drinking water communities, due to potentially aerated radon from source water are much smaller (in most cases 2 to 4 orders of magnitude smaller) than the risks due to radon in water if no treatment were applied.

EPA is aware that some states allow no emissions from PTA regardless of downwind risks. EPA has reviewed the few available data on removal of radon from air by carbon. Based on these data, EPA believes air phase removal of radon by GAC may not be feasible. Systems trying to meet local air emissions requirements may need to rely on GAC in the water phase.

c. *Granular activated carbon.* Pilot plant studies have shown that granular activated carbon (GAC) is capable of removing radon in drinking water at efficiencies of 90 to 99 percent (Kinner et al., 1989). The efficiency of removal is dependent upon radon concentration,

the mass of carbon in the GAC column, empty bed contact time (EBCT) and contactor configuration (i.e., upflow or downflow). The pilot studies have shown radon to require a longer EBCT than other adsorbable (e.g., organic) materials. Thus, to achieve a 90 percent removal efficiency with a radon influent concentration of 10,000 pCi/l, an EBCT of approximately 70 minutes may be required. The need for such a lengthy EBCT means that GAC may not be practical for large municipal treatment systems (EPA, 1987b) and it is therefore not considered BAT.

Another disadvantage associated with the use of carbon for radon removal is the buildup of radiation inside and surrounding the GAC contactor. The radionuclides that may build up on the GAC media are the progeny of radon, specifically the radioactive isotopes of lead, polonium and bismuth. The short-lived radon progeny include Pb-214 and Bi-214. Long-lived radon progeny include Pb-210, Bi-210, and Po-210. The level of gamma radiation surrounding the GAC vessel depends on the amount of radon removed; gamma intensity drops sharply with increased distance from the GAC vessel. Due to the buildup of radon daughter products, such as lead-210, a beta particle emitter, the GAC unit can become a source of low-level radiation, and may present a disposal problem as well. Studies have shown that the radiation level is usually less than 1.0 mR/hr. at a distance of three (3) feet from the GAC tank surface (Kinner et

al., 1989). EPA's guidelines for radioactive waste disposal (EPA, 1990a) provide guidance on the disposal of GAC waste containing naturally occurring radionuclides, and appropriate occupational guidance.

The estimated cost for small GAC water treatment systems for 80 percent removal of radon ranges from \$6.60/1,000 gallons of water serving 25 to 100 people to \$1.40/1,000 gallons of water serving 3,000 to 10,000 persons, exclusive of the cost to dispose of spent carbon. Due to the problems identified above, i.e., of radiation build-up, waste disposal, and contact time, the Agency has judged that GAC cannot be designated as BAT for radon removal (EPA, 1987b; 1988e; 1991i).

3. *Uranium.* The Agency proposes that, of the technologies capable of removing uranium from source water, coagulation/filtration, ion exchange, lime softening and reverse osmosis fulfill the requirements of the SDWA as BAT for uranium removal. These technologies have demonstrated effective uranium removal, are currently available, have been installed in public water supplies, and are compatible with other water treatment processes in different regions. The full range of technical capabilities for each of these proposed BATs is discussed in the EPA technologies and costs document for uranium (EPA, 1985b), and summarized below.

a. *Coagulation/filtration.* Laboratory and pilot plant studies have shown that pH and coagulant dosage significantly impact uranium removal efficiency in water treatment. Iron and aluminum based coagulants are generally more effective in aiding the removal process at pH values near 6 and 1. Removal by coagulation appears to be low at pH 8 due to stability and charge characteristics of uranyl species in solution. In one study, removal efficiencies of greater than 80 percent were reported (Sorg, 1988) in tests using 20 mg/l doses of ferric sulfate, ferrous sulfate, or aluminum sulfate coagulants. Influent uranium levels were about 83 µg/l in that study. Coagulation/filtration has been demonstrated to achieve removal efficiencies as high as 95 percent when using aluminum sulfate dosed at 10 mg/l or more, at pH 10 (Sorg, 1988).

Coagulation/filtration as a new process designed specifically to remove uranium may not be cost effective, particularly for smaller utilities. However, where the reduction of turbidity in the source water is also a concern, this method can be very effective.

Estimated costs for an existing coagulation/filtration facility to modify treatment for 60% removal of uranium from ground water sources range from \$4.40/1,000 gallons of water for systems serving a population of 25–100 persons, to \$0.02/1,000 gallons of water for systems serving over 1,000,000 persons.

b. *Ion exchange.* Anion exchange systems for the removal of uranium and other soluble ions have demonstrated uranium removal efficiencies of between 65 and 99 percent. Ion exchange devices are available for most applications. The estimated costs for removal of uranium from ground water by ion exchange range from \$4.10/1,000 gallons of water treated for systems serving 25–100 persons, to \$1.00/1,000 gallons of water treated for systems serving more than 1,000,000 persons. Disposal of concentrated waste brine must also be considered, as discussed above.

c. *Lime softening.* Lime softening is capable of achieving removal efficiencies for uranium of up to 99 percent. At optimum pH levels of 10.6 to 11.5 removal efficiencies of 85 to 99 percent can be achieved. Best results can be achieved by increasing the dosage of lime to approximately 250 mg/L and maintaining the pH above 11. Lower dosages of $\text{Ca}(\text{OH})_2$, 50 to 100 mg/l, have achieved 85 percent uranium removal. This treatment should be given serious consideration if removal of hardness from source water is also a desired objective. It may not be cost effective for a system to build a new lime softening treatment facility specifically to remove uranium. The estimated cost to modify an existing lime softening treatment facility to remove uranium from ground water ranges from \$4.20/1,000 gallons of water serving 25–100 persons to \$0.03/1,000 gallons of water serving more than 1,000,000 persons.

d. *Reverse osmosis.* Reverse osmosis (RO) membranes are capable of removing uranium and many other contaminants in source water, at high efficiencies. RO has been used primarily for removing total dissolved solids (TDS) from water in the treatment of brackish and sea waters for desalinization purposes. At reduced pressures RO is adaptable to fresh water sources. Using cellulose acetate membranes, at 250 psi pressure, RO has successfully achieved 98 to 99.4 percent removal efficiencies. However, RO performance is adversely affected by the presence of turbidity, iron, manganese, silica or scale producing constituents in source water. If pretreatment is not already in place to remove these constituents, the cost to install the

pretreatment facility would be an important factor.

The RO system is adaptable to all size systems with costs ranging from \$6.20/1,000 gallons for systems serving 25–100 persons to \$0.89/1,000 gallons for systems serving over 1,000,000 persons. If reducing TDS is also a goal of the treatment process then reverse osmosis is a very cost effective solution for the removal of uranium from source waters. Disposal of waste brine, the reject flow representing 20 to 50 percent of the feed water, and the quantity of available feed (source) water to accommodate this technology, would require consideration by a water system in its initial evaluation of alternative technologies for radium removal.

4. *Beta and photon emitters.* The Agency proposes that of the technologies considered to remove beta particle emitters from drinking water, ion exchange and reverse osmosis would fulfill the requirements of the SDWA as BAT for gross beta particle removal. The subject radionuclides originate from the nuclear fuel cycle, defense related industrial activities, institutions such as hospitals, research foundations and universities, commercial/industrial users of radioisotopes, and atmospheric or surface detonation of nuclear devices. Some beta-emitting radionuclides originating from such sources have occurred in drinking water sources and have been partially removed by drinking water treatment processes.

Levels of gross beta above the maximum contaminant level are likely to occur only in transient situations following a contaminating event. The following technologies may be effective in lowering the contaminant level below the MCL value. The full range of technical capability of the proposed BATs is summarized in the EPA document "Technologies and Costs for the Removal of Man-Made Radionuclides from Potable Water Supplies" (EPA, 1986b). The technologies listed are available and compatible with other water treatments in all regions of the United States.

a. *Ion exchange.* Ion exchange has been successfully employed by the nuclear power industry in treating liquid radioactive wastes as well as chemical, laboratory, and laundry wastes containing various ionic species. Cation exchange resins have exhibited a 95 to 99 percent removal efficiency for low level and trace amounts of the following contaminants: barium-137, barium-140, cadmium-115, cesium-137, lanthanum-140, scandium-46, and strontium-89. Anion exchange resins have exhibited a

94 to 99 percent removal efficiency for the following contaminants: niobium-95, tungsten-185, zirconium-95, scandium-46, and yttrium-91. Mixed bed ion exchange may effectively remove between 90 and 99.9 percent of all contaminants listed above. Therefore ion exchange technology is proposed as BAT for beta and photon emitters. Disposal of waste brine may pose difficulty due to the high concentration of radionuclides in the brine, the availability of disposal options for the liquid wastes, and State or Federal limitations which may prevail.

The cost for removal of beta-emitting radionuclides utilizing ion exchange would be highly dependent upon type and amount of contamination. The cost supplement (EPA, 1987c) to the above cited Technologies and Cost document contains estimated cost for removal of beta emitters from public water systems using two-bed ion exchange system (i.e., cationic and anionic).

b. *Reverse osmosis.* Reverse osmosis (RO) membranes can effectively remove more than 99 percent of radioactive contaminants such as strontium, cesium, and iodine from water. Pilot studies have demonstrated removal efficiencies of 90 to above 99 percent of dissolved iodine-131, strontium-89, and cesium-134. The cost of removing man-made radionuclides from source water utilizing RO may be similar to the costs cited in Tables 7, 8 and 9 for removal of uranium from drinking water. However, cost would be highly dependent on type and degree of contamination.

RO performance is adversely affected by the presence of turbidity, iron, manganese, silica, or scale-producing constituents in the source water. If the pretreatment is not already in place to remove these constituents, the cost to install the pretreatment facilities may be an important factor. Disposal of waste brine may be problematic due to the high concentration of radionuclides in the brine, or due to local requirements or regulations affecting discharge.

The cost supplement (EPA, 1987c) for the Technology and Cost document cited above contains estimated cost for removal of beta emitting radionuclides from public water systems using reverse osmosis technology.

c. *Coagulation/filtration.* Some beta-emitting radionuclides which exist as suspended material in water may be removed by coagulation/filtration. In laboratory studies involving many soluble radionuclides, it was reported that coagulation employing aluminum sulfate, ferric chloride and/or ferrous sulfate was more effective for removal of soluble cations of valences 3, 4 or 5 which include: niobium-95, cerium-141,

phosphorus-32, zirconium-95, cobalt-58 and -60, ruthenium-103, and sulfur-35.

Full-scale studies in municipal filtration plants downstream from nuclear reactor sites have indicated removal of chromium-51, scandium-46, arsenic-76 and seven other nuclides at efficiencies of 28 to 87 percent, using alum as the coagulant. Activated silica or clay can be added when needed to enhance flocculation, coagulation and precipitation. Ninety percent removal of strontium requires iron coagulant dosages greater than 500 mg/l at a pH of 11. Efficiencies of removal of specific radionuclides by the coagulation process can range from 0 to 99 percent.

Due to the variability cited above in the removal efficiencies, and because of the lack of information on removal of many beta emitting radionuclides, EPA proposes that coagulation/filtration does not meet the requirements to be proposed as a BAT for beta emitters.

d. *Lime softening.* Lime softening with soda-ash addition can remove approximately 90 percent of strontium and other radiological contaminants present in source water. To achieve this percent removal the sodium carbonate concentration should be three times the equivalent permanent calcium hardness. Using 68 to 205 mg/l of lime and 68 to 154 mg/l of soda ash, 90 percent removal of the following radionuclides may be achievable: barium-140, cadmium-115, zirconium-95, lanthanum-140, scandium-46, niobium-95, strontium-89, and yttrium-91.

Due to the lack of information on removal of many of the beta emitting radionuclides addressed by this proposed regulation, EPA proposes that lime softening not be designated as a BAT for beta emitters.

5. *Alpha emitting radionuclides.* In order to determine BAT for the removal of alpha-emitting radionuclides, the Agency required information regarding the identity and treatability of those radionuclides which occur or may occur in potable water supplies (other than radium, radon and uranium). Alpha emitters identified above that may occur in water systems include polonium-210 (Po-210), thorium 228,230, and 232 (Th-228, 230, 232) and at very low levels, plutonium 238, 239 and 240 (Pu-238, 239, 240).

EPA summarized available treatment data from field studies and from public water systems in the document "Technologies and Costs for the Removal of Alpha Emitters from Potable Water Supplies (EPA, 1991k). EPA has found no treatability information on the radionuclide thorium, a fact likely due to the insolubility of and the difficulties associated with measuring this

contaminant. Relatively little information was available on treatability of plutonium in water supplies. However, plutonium appears to be removed by coagulation and filtration technology, particularly where the contaminant is associated with turbidity in surface waters or with colloidal hydroxide particulates. Surface water contaminated with trace amounts plutonium 239 and 240, such as Lake Michigan (fallout derived plutonium) and the Savannah River (downstream from a nuclear power plant), have been treated for industrial and municipal use with coagulation/filtration technology. Raw influent waters contained 1 to 2 femtocuries of plutonium per liter of water. Removals of plutonium at these facilities have been recorded in the range of 25 to 96 percent. The addition of carbonates through lime and soda ash appears to contribute to the coagulation and removal of colloidal plutonium from natural surface waters. Plutonium removal efficiency was found to increase with higher plutonium concentrations. Nonetheless, in regard to the application of coagulation/filtration for removal of plutonium from water, EPA finds that the wide range of efficiencies that have been documented preclude its designation as a BAT for alpha emitters.

EPA has undertaken to identify BATs that effectively remove polonium-210 from drinking water to achieve compliance with the gross alpha standard. The results of treatability studies conducted in Maine on well water containing high levels of polonium-210 are discussed in detail in the Cost and Technologies Document cited above. In the Maine field study conducted over 2 months during 1990-1991, anion exchange, reverse osmosis, and granular activated carbon (GAC) were tested. These tests showed (after correction of some clogging and fouling of the ion exchange and carbon units) reverse osmosis with the highest removal rates (98-99%), and GAC (69-93%) and ion exchange (52-83%) showing somewhat lower removal rates. Water pH may affect polonium removal rates for GAC and ion exchange, but this has not been documented.

The Maine treatability studies and the Technologies and Cost document form the basis for a decision by EPA to propose a BAT for removal of alpha emitters. RO has provided the highest removal efficiencies and is proposed as BAT for alpha emitter removal.

C. Waste Treatment and Disposal

The treatment and disposal of waste by-products generated by the treatment

processes increases overall water treatment costs, especially for small systems. However, in establishing BAT, EPA identifies the treatment and disposal technologies that are reasonably available for large metropolitan regional drinking water systems (i.e., systems which service

50,000 to 75,000 persons). Disposal of wastes from treatment for radionuclides does not significantly increase the total treatment costs for large systems. Several waste disposal techniques and estimates of associated costs are identified in Table 11. Technologies and costs related to the disposal of the

granular activated carbon that may in some cases be used for radon removal have not been determined by EPA. GAC is not a BAT for radon removal for reasons outlined in section B, part 2(c), above.

TABLE 11.—RANGE OF BRINE AND SLUDGE DISPOSAL COSTS IN REMOVAL OF RADIONUCLIDE CONTAMINANTS ¹

[Cents/1,000 Gallons of Water Treated]

Treatment process	Direct discharge	Discharge to sewer	Evaporation pond/land	Chemical precipitation
Brine Disposal:				
Ion Exchange.....	(²)	4-110	20-250	30-350
Reverse osmosis.....	2-95	10-230	(²)	(⁴)
Treatment process	Discharge to sewer	Non-mechanical dewatering and land disposal (³)	Dewatering and land disposal (³)	
Sludge Disposal:				
Coagulation/Filtration.....	1-190	65-360	75-2,800	
Lime Softening.....	(²)	30-600	(⁴)	

Notes:

¹ From "Technologies and Costs for the Treatment and Disposal of Waste Byproducts from Water Treatments for the Removal of Inorganic and Radioactive Contaminants" (EPA, 1986d). Cost ranges represent disposal costs for very large to very small water systems.

² Data not available.

³ Non-mechanical dewatering alternatives for sludges include sand drying beds and dewatering lagoons.

⁴ Disposal option too expensive.

⁵ Mechanical dewatering may include utilization of pressure filtration.

Liquid wastes, or brines, are generated by ion exchange, reverse osmosis, and activated alumina. The most economical disposal method for concentrated brines is discharge to a sanitary sewer, and for reverse osmosis, direct discharge of the concentrated waste stream to a receiving body of water, if these methods are acceptable to applicable regulatory agencies and meet Clean Water Act requirements for direct and indirect discharges to surface water. Underground injection may be an option, subject to the requirements of the Underground Injection Control Program. Other possible though more expensive alternatives include evaporation pond dewatering followed by land disposal, and chemical precipitation followed by non-mechanical drying and land disposal. Sludges are generated by coagulation/filtration, greensand filtration, and lime softening. The most economical disposal method for sludges is discharge to a sanitary sewer. Again, this method may be restricted by state or local requirements and pre-treatment requirements under the Clean Water Act (see generally 40 CFR part 403). An alternative option may be non-mechanical drying (lagoons or drying beds) followed by land disposal. Mechanical methods tend to be higher in cost, though technically feasible, for all sludges.

At the present time there are no federal regulations which specifically address the disposal of water treatment wastes containing radionuclides. However, the selection of waste by-product disposal alternatives may be determined by federal, state, and local regulatory constraints and site specific conditions. Regulatory constraints may include industrial pretreatment requirements for sanitary sewer discharges (including requirements applicable to sewage sludge use and disposal under section 405 of the Clean Water Act), requirements under the Underground Injection Control (UIC) program, RCRA requirements for hazardous waste disposal and protection of groundwater, and effluent limitations and water-quality based limits for the discharge of some contaminants into local receiving waters (groundwaters and surface waters) under the NPDES program. Site-specific conditions which influence waste management include the availability of sewage disposal, location of disposal sites, climatic factors, cost of land, and other local or regional factors including available manpower and infrastructure characteristics.

EPA's report entitled "Suggested Guidelines for the Disposal of Naturally Occurring Radionuclides Generated by Drinking Water Treatment Plants," (EPA, 1990a) outlines the Agency's

understanding of the technical issues and the existing regulatory framework that may be relevant to systems which remove naturally-occurring radioactive substances from drinking water supplies. In this report, EPA recommends types of treatment and disposal options and institutional controls which would be pertinent for solid and liquid wastes containing radioactive contaminants, at various ranges of concentration. The report also makes recommendations regarding radiation in the water treatment plant and protection of workers at the plant and during waste disposal operations. EPA solicits public comment on its waste disposal guidance, and waste disposal issues in general.

EPA and others have studied the treatment technologies available for the removal of radionuclides from drinking water and characterized some of the waste residuals of treatment. These studies were conducted on source waters naturally high in radioactivity and produced data which may be useful for the purpose of characterizing solid and liquid wastes from the treatment of drinking water and for comparison with the EPA Suggested Guidelines cited above. Table 12 summarizes some data that EPA has gathered on water treatment wastes containing radium and uranium.

Table 13 outlines the options for sludge disposal suggested in the EPA guidelines. Notwithstanding these suggested guidelines, solid wastes and liquid wastes generated by drinking water treatment plants should be disposed of in compliance with Federal, State and local requirements, State-

adopted criteria of 40 CFR part 257, which contains RCRA groundwater protection criteria, and municipal solid waste landfill regulations under 40 CFR part 258.

Similarly, from the same EPA report cited above, EPA guidelines were

developed for disposal of liquid wastes, or brines, which result from the treatment of drinking water containing radionuclides. These are outlined in Table 14. EPA solicits public comment on the waste disposal guidance and estimated disposal costs.

TABLE 12.—SUMMARY OF WATER TREATMENT DATA ON WASTES CONTAINING NATURAL RADIONUCLIDES

Treatment wastes	References	Concentration range
Lime softening sludges.....	(EPA, 1985d)	
Ra-226.....		1-22 pCi/g (dry).
Ra-228.....		2-12 pCi/g (dry).
Ion exchange.....	(EPA, 1987f)	
Chemical clarification filter cake, uranium.....		57-171 pCi/g (dry).
Lime softening backwash.....	(EPA, 1985d)	
Ra-226.....		6-50pCi/l.
Ion exchange brine/regen		
Radium—typical.....	(Schliekelman, 1976).....	110-530 pCi/l.
—Peak.....		3,500 pCi/l.
Uranium.....	(Schliekelman, 1976 and EPA, 1985d).....	up to 610 pCi/l.
Reverse osmosis waste.....	(Sorg et al., 1980).....	
Ra-226.....		7-38 pCi/l.
Mang. and iron treatment filter backwash.....	(EPA, 1985d and EPA, 1987a)	
Ra-226.....		21-106 pCi/l.
Ra-228.....		5.7-83 pCi/l.

TABLE 13.—DISPOSAL GUIDELINES FOR RADIOACTIVE SOLID WASTES RESULTING FROM DRINKING WATER TREATMENT PROCESSES ¹

Waste characteristics	Disposal option
I. Solids/sludges containing less than 3 pCi/g of radium or lead-210, or less than 30 pCi/g uranium.	Sludge should be dewatered, and mixed in landfill.
II. Solids/sludges containing 3 to 50 pCi/g of radium or lead-210, or 30 to 500 pCi/g uranium.	Sludge should be dewatered, and disposed of within a stabilized landfill to isolate and to avoid inappropriate usage of the site.
III. Solids/sludges containing 50 to 2,000 pCi/g of radium or lead-210, or 500 to 2,000 pCi/g of uranium.	Case-by-case determination, to include consideration of standards for uranium mill tailings (40 CFR 192), NARM disposal, and long-term institutional control of disposal sites. RCRA hazardous waste units should also be considered. NRC provisions may apply.

TABLE 13.—DISPOSAL GUIDELINES FOR RADIOACTIVE SOLID WASTES RESULTING FROM DRINKING WATER TREATMENT PROCESSES ¹—Continued

Waste characteristics	Disposal option
IV. Solids/sludges containing more than 2,000 pCi/g of natural radioactivity.	Should be disposed of in a low-level radioactive waste disposal facility operated under the provisions of the Atomic Energy Act, as amended, or at a State or EPA-permitted facility for NARM disposal. Uranium recovery may be possible. NRC provisions may apply. Dept. of Transportation regulations would apply.

Note: Water treatment facilities should keep records of the amount and composition of radioactive wastes they generate, and the manner and location of disposal.

¹ From EPA Suggested Guidelines (EPA, 1990a).

TABLE 14.—DISPOSAL GUIDELINES FOR RADIOACTIVE LIQUID WASTES GENERATED BY WATER TREATMENT PLANTS ¹

Disposal option	Requirements (Federal and other)
A. Disposal into surface water.	(1) Federal, State and local discharge limits and NPDES permit requirements apply.

TABLE 14.—DISPOSAL GUIDELINES FOR RADIOACTIVE LIQUID WASTES GENERATED BY WATER TREATMENT PLANTS ¹—Continued

Disposal option	Requirements (Federal and other)
B. Discharge into sanitary sewers (if Ra-226 is less than 400 pCi/l, Ra-228 less than 800 pCi/l, total uranium less than 1 µCi/l, and yearly total discharge less than 1 curie).	(1) State limits on discharge of hazardous or radioactive wastes. (2) Limits on discharge of radium and uranium into sanitary sewers—per NRC standards for discharge by licensees (10 CFR 20, part 303). (3) Federal, State, and local pretreatment requirements.
C. Disposal of radioactive wastes through injection wells (under conditions consistent with 40 CFR 144 classifications of wells). Shallow injection banned.	(1) Authorization of any injection of liquid wastes under the Underground Injection Control (UIC) program regulations in 40 CFR 144.6(a)(2), and 144.12(c).
D. Evaporation, precipitation, drying, or other treatment.	(1) Residual solids should be disposed per solid waste regulations and per EPA guidelines for water treatment solid wastes (EPA, 1990a).

¹ From EPA Suggested Guidelines (EPA, 1990a).

D. Analytic Methods

The SDWA directs EPA to set an MCL for contaminants for which there are MCLGs, "if, in the judgement of the Administrator, it is economically and

technologically feasible to ascertain the level of such contaminants in water in public water systems." (SDWA section 1401[1][C][ii]). NPDWRs are also to "contain[s] criteria and procedures to assure a supply of drinking water which dependably complies with such maximum contaminant levels; including quality control and testing procedures to insure compliance with such levels." (SDWA section 1401[1][D]). The analytic methods described and evaluated here are the testing procedures EPA identified to insure compliance with the MCLs. EPA evaluated the availability, cost, and the performance of these analytical techniques, as well as the ability of laboratories to use these methods to measure radionuclide contaminants consistently and accurately in a compliance monitoring setting.

The reliability of analytic methods at the maximum contaminant level is critical to implementing and enforcing

the MCLs. Therefore, each analytical method was evaluated for accuracy or recovery (lack of bias) and precision (good reproducibility over the range of MCLs considered). The primary purpose of this evaluation is to determine:

- Whether analytical methods are available to measure the regulated radionuclide contaminants in drinking water;
- The ability of recently developed analytical method(s) to measure radionuclide contaminants in drinking water;
- Reasonable expectations of technical performance by analytical laboratories conducting routine analysis at or near the MCL levels; and
- Analytical costs.

The selection of analytical methods for compliance with these regulations includes consideration of the following factors:

(a) Reliability (i.e., precision/accuracy of the analytical results over a range of concentrations, including the MCL);

(b) Specificity in the presence of interferences;

(c) Availability of adequate equipment and trained personnel to implement a national compliance monitoring program (i.e., laboratory availability);

(d) Rapidity of analysis to permit routine use; and

(e) Cost of analysis to water supply systems.

1. Description of analytic methods.

Analytical methods exist to measure each radionuclide contaminant covered by today's proposed regulations. Table 15 lists these analytical methods. EPA believes these methods are technically sound, economical, and generally available for radionuclide monitoring, and is proposing their use for monitoring to determine compliance with the MCLs.

TABLE 15.—PROPOSED METHODOLOGY FOR RADIONUCLIDE CONTAMINANTS

Contaminant	Methodology	References (Method or Page Number)								
		EPA ¹	EPA ²	EPA ³	EPA ⁴	SM ⁵	ASTM ⁶	USGS ⁷	DOE ⁸	Other
<i>Naturally Occurring:</i>										
Gross alpha and beta.....	Evaporation.....	900.0	pp. 1-3	00-01	p1	7110 B	D 1943-81	R-1120-76		
Gross alpha	Co-precipitation			00-02						
Radium 226.....	Radon Emanation	903.1	pp. 16-23	Ra-03	p. 19	750-Ra B	D 3454-86	R-1141-76		⁹ N.Y.
	Radiochemical.....	903.0		Ra-05						
Radium 228.....	Radiochemical.....	904.0	pp. 24-28	Ra-05	p. 19	7500-Ra D*		R-1142-76		⁹ N.Y., ¹⁰ N.J., ¹¹ 913, ¹² LS ¹² LC
Radon 222	Liquid Scintillation									
	Lucas Cell.....									
Uranium	Radiochemical.....	908.0				7500-U B	D 3972-82			
	Fluorometric.....	908.1				7500-U C	D 2907-83	R-1180-76	E-U-03	
	Alpha Spectrometry			00-07	p. 33			R-1182-76	E-U-04	
<i>Man-Made:</i>										
Radioactive Cesium	Precipitation	901.0	pp. 4-5			7500-Cs B		R-1110-76	E-Cs-01	
Radioactive Iodine	Precipitation	902.0			I-01	7500-I B	D 2334-88			
Radioactive Strontium 89, 90.	Precipitation	905.0	pp. 29-33		p. 65	7500-Sr B		R-1160-76		
	Radiochemical.....		pp. 108-114	Sr-04					E-Sr-01	
Tritium.....	Liquid Scintillation	906.0	pp. 34-40	H-02	p. 87	7500-3H B	D 2476-81 (87) D-3649-85	R-1171-76		
Gamma and photon emitters.	Gamma Ray Spectrometry.	901.1							4.5.2.3	

¹ "Prescribed Procedures for Measurement of Radioactivity in Drinking Water," EPA Environmental Monitoring and Support Laboratory, Cincinnati, OH (EPA-600/4-80-032, August 1980. (EPA, 1980))

² "Interim Radiochemical Methodology for Drinking Water," EPA-600/4-75-008, March 1976. (EPA 1976)

³ Eastern Environmental Radiation Facility, Montgomery, AL 36109, "Radiochemical Procedures Manual," EPA 520/5-84-006, August 1984. (EPA, 1984a)

⁴ "Radiochemical Analytical Procedures for Analysis of Environmental Samples," EMSL-LV-0539-17, March 1979. (EPA, 1979b)

⁵ "Standard Methods for the Examination of Water and Wastewater," 17th edition, American Public Health Association, American Water Works Association, Water Pollution Control Federation, 1989. (APHA, 1989)

⁶ 1989 Annual Book of ASTM Standards, Vol. 11.02, American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103. (ASTM, 1989)

⁷ Methods for Determination of Radioactive Substances in Water and Fluvial Sediments," Book 5, 1989, Techniques of Water-Resources Investigations of the United States Geological Survey, Chapter A5. (USGS, 1989)

⁸ Environmental Measurements Laboratory, U.S. Department of Energy, "EML PROCEDURES MANUAL, 27th edition." (DOE, 1990)

⁹ "Determination of ²²⁶Ra and ²²⁸Ra (Ra-02), Radiological Sciences Institute Center for Research—New York State Department of Health, January 1980 (Revised June 1982). (NY State DOH, 1982)

¹⁰ "Determination of Radium 228 in Drinking Water," State of New Jersey—Department of Environmental Protection—Division of Environmental Quality—Bureau of Radiation and Inorganic Analytical Services, August 1990. (NJ DEC, 1990)

¹¹ Method 913—Radon in drinking water by liquid scintillation, "Environmental Monitoring and Support Laboratory, Las Vegas, NV. (EPA, 1991q)

¹² Appendix D, Analytical Test Procedure, "The Determination of Radon in Drinking Water," p. 22, Two Test Procedures for Radon in Drinking Water, Interlaboratory Collaborative Study, EPA/600/2-87/082, March 1987. (EPA, 1987e)

EPA believes that the analytical methods listed in Table 15 are technically and economically available

for radionuclide monitoring. Many of the listed analytical methods have been used for a number of years in water

analyses under the Interim Drinking Water Regulations (see 40 CFR part 141, subpart C) and in determining

compliance with the current MCLs (see 40 CFR part 141, subpart B). EPA has updated the original references to the most recent editions of the manuals and references, when applicable, i.e., EPA, Standard Methods (SM), American Society for Testing Materials (ASTM), United States Geological Survey (USGS) and Department of Energy (DOE). Several more recently developed methods are also listed. In addition, EPA Method 909, "Determination of Lead-210 in Drinking Water" would be used for the unregulated contaminant monitoring for lead-210 (EPA, 1982).

The reliability of these methods has been demonstrated by a history of many years' use by state, federal and private laboratories. Most of the methods above have undergone an interlaboratory collaborative study (multilaboratory tested), with the remainder being subjected to single laboratory tests. The majority of the validation studies were EPA performed or sponsored. Those validations performed by accredited standard bodies, i.e., SM, ASTM, etc. were reviewed by EPA personnel and determined to be acceptable. The N.Y. method for radium 226 and 228 had "limited approval", previous to the discontinuation of alternate test procedures (ATPS) in the drinking water program. The N.J. method for radium 228 is currently under review. EPA requests comments on whether these techniques should be considered available for purposes of this proposed rule.

Below is a brief description of the proposed radionuclide techniques listed in Table 15. Analysis generally requires some sample preparation followed by counting by one of several methods. Radiation counting instruments include various types of gas-flow proportional counters, scintillation cells and scintillation counters that are suitable for measuring alpha- or beta-emitting radionuclides, and sodium iodide or germanium detectors coupled to multichannel analyzers are available for gamma spectrometry. General description of the different basic counting methods are presented, followed by brief discussions of the methods specific for each analyte. Copies of the complete methods are available in the Drinking Water Docket, as well as in several published reference manuals. EPA refers readers to the references for information on precision, accuracy, counting efficiency, background determination, sample and source preparations, interferences and calibration information on the proposed analytical methods.

a. Counting methods. i. Alpha Emitting Radionuclides (Gross alpha particle

*activity, Radium-226, Radon-222 and Uranium)—Alpha Counting Methods—*Alpha particles are characterized by an intense loss of energy in passing through matter. This intense loss of energy is used in differentiating alpha radioactivity from other types by the dense ionization or intense scintillation it produces. Alpha counting methods, which measure alpha radioactivity, are applicable in the determination of gross alpha particle activity, radium-226, radon-222 and uranium. Alpha radioactivity can be measured, after various sample preparations, by one of several types of detectors in combination with appropriate electronic components. The techniques for measuring the alpha emitters use gas-flow proportional counters, scintillation cell systems and liquid scintillation counters, in conjunction with electronic components such as high voltage power supplies, preamplifiers, amplifiers, scalars and recording devices. Additional techniques using fluorometry and alphaspectrophotometric techniques are being proposed for uranium analysis.

Proportional Counting. In proportional counting, alpha particles are introduced to the sensitive region of a proportional counter and produce ionization of the counting gas. The electrons are accelerated towards the anode, producing secondary ionization and developing a large voltage pulse by gas amplification. The total ionization is proportional to the primary ionization produced by the alpha particle. Electronic voltage discrimination allows for differentiation of alpha particles from beta particles.

Scintillation Counting. In scintillation counting, the alpha particle transfers energy to a scintillator disk, such as zinc sulfide, which is enclosed within a light-tight container. The transfer of energy to the scintillator disk results in the production of light at a wavelength characteristic to the scintillator, and with an intensity proportional to the energy transmitted from the alpha particle. The scintillator disk is placed next to the sample and on the face of the photomultiplier tube. The light from the scintillator strikes the photocathode producing electrons, which are emitted at levels proportional to the intensity of the light. The photoelectrons are amplified by the multiplier phototube and a voltage pulse is produced at the anode for measurement. An electronic scaler (counter) records the individual pulses which are proportional to the number of alpha particles striking the scintillation detector.

A scintillation cell system for radon gas counting performs alpha particle counting using the principles of scintillation counting as described above. The exceptions are that a scintillation flask ("Lucas Cell", a 100-125 ml metal cup coated on the inside with zinc sulfide and having a transparent window) replaces the scintillation disk in the apparatus. A counting system compatible with the scintillation flask is incorporated. The scintillation cell system is used for the specific measurement of radon. Radium-226 can also be measured by Lucas Cell counting of its radon-222 progeny.

Direct, low volume liquid scintillation (liquid scintillation) counting of alpha emitters with a commercially available instrument is also employed in the proposed methods. A liquid scintillator or organic phosphor is combined in an appropriate mineral oil or other organic base scintillator "cocktail" with the water sample. Mixing achieves a uniform dispersion before counting. This replaces the planchet or disk preparation that occurs before the counting step in the scintillation technique.

Analyses performed using a fluorometer require sample preparation as mentioned above. Fluorometry is used in one of the procedures for uranium in this proposal. The fluorometer measures the fluorescence of the uranium from the sample that is exposed to ultra violet light from the instrument. The response to this excitation is proportional to the concentration of the analyte in the sample.

Alpha spectroscopy involves identifying specific alpha isotopes by converting the kinetic energy of an alpha particle to a charge pulse whose magnitude is proportional to the alpha particle energy absorbed by the detector. The pulse is routed to a multichannel analyzer where energy discrimination can be performed. This alpha spectrometer is employed in some of the techniques for the measurement of uranium.

ii. Beta Emitting Radionuclides (Gross beta particle activity, Radium-228, Cesium-134 and -137, Iodine-131, Strontium-89 and -90 and Tritium)—Beta Counting Methods: The large difference in the specific ionization energy produced by alpha and beta particles permits pulse discrimination between these radiations to allow for identification. Beta particles are characterized as fast electrons emitted by radioactive nuclei. The beta particles from a particular radioactive element are not all emitted with the same energy

but with energies ranging from zero up to a maximum value which is characteristic of the nuclide. This fact makes it extremely difficult to differentiate among beta emitters by energy discrimination.

Beta counting methods, which measure beta radioactivity, use one of several types of instruments (counters) that consist of a detector and an amplifier, power supply, and scaler, etc. As in alpha counting, there are various sample preparations or chemical separations necessary prior to counting. The most widely used instruments are proportional counters, but scintillation systems are also used. These counting techniques are applicable for the measurement of beta radioactivity by using beta emitting standards for calibration and determination of counting efficiency in the analyses.

iii. *Gamma and Photon Emitting Radionuclides-Gamma Counting Method:* Gamma rays are high energy photons with discrete energies that are a penetrating form of radiation. This characteristic can be used to measure samples of any form, as long as calibration standards of the same form are available and are counted using the same geometry. Individual calibration standards are used for identifying and quantifying contributing gamma emitting radionuclides using gamma counting or gamma spectrometry. Gamma counting is performed using solid detectors (NaI or germanium), as opposed to gas-filled detectors.

In gamma-ray analysis or counting, the detectors produce light photons (scintillations) or electron-hole pairs that are amplified into electrical pulses within the counting system. These output pulses, which are directly proportional to the amount of energy produced, are counted using a scaler or analyzed by pulse height to produce a gamma-ray spectrum, depending on the detector employed. The use of a multichannel analyzer allows for energy discrimination and the identification and quantification of the individual nuclides.

b. *Specific analytic methods*—i. *Gross alpha and gross beta activity.* The gross alpha and gross beta activity methods are the simplest of radioanalytic methods. A portion of the water sample is simply evaporated to dryness on a planchet, which is then counted for alpha and beta activities. The different types of alpha and beta counting equipment used was described above. The co-precipitation method, usually applicable for gross alpha analysis, adds one chemical separation step before counting to reduce the total solids present, thereby reducing self

absorption and improving counting efficiency. It also allows for the use of larger samples for greater sensitivity.

In addition to being used to determine compliance with the MCLs, these methods would be used as screening procedures to determine if additional analyses for the specific radionuclides are necessary, if the appropriate standard is used for calibration. Gross alpha measurement would be used as a screen for radium 226 and uranium, and gross beta would be used as a screen for radium 228. If gross alpha methods are to be used for screening for radium 226 and uranium compliance, the labs however, would be required to calibrate the counter for uranium. Laboratories would also be required to generate standard curves for their counters showing the change in counting efficiency versus the total solids in the water sample (for both radium and uranium), and use these curves to correct for lower counting efficiencies found with high solids samples. If these corrections are not made, gross alpha measurements would not be considered a valid screen for radium 226 and uranium for determining compliance with the MCLs. Valid gross beta measurements can be made with waters having a much larger dissolved solids content than for alpha emitters. In beta counting efficiency does not change appreciably with solids in water samples but generation of self absorption curves is still required. EPA recommends use of strontium 90 for the beta screen for radium 228. The gross alpha screen would no longer be used to screen for the presence of radium 228 as in the current interim monitoring requirements, as radium 228 is a beta emitter and alpha screening could not be expected to reliably serve as a screen.

The Agency believes that a pure alpha particle emitter i.e., thorium 230 should be used as a standard for calibration for gross alpha activity. Past use of americium-241 tended to bias analytic results low due to the over estimate of counting efficiency because of its higher energy alpha particle. Cesium 137 is recommended for calibrating the gross beta screen.

A co-precipitation method for gross alpha activity has also been included. This method was reviewed and evaluated in the report, "Test Procedure for Gross Alpha Particle Activity in Drinking Water" (EPA, 1985c). Water samples that have high dissolved solids (>500 mg/l), are likely to have high self absorption of alpha particles which reduces the sensitivity of the measurement. When high solids are present, the Agency recommends use of the coprecipitation method.

ii. *Radon.* EPA is proposing two methods for measurement of radon in water. These are direct low volume liquid scintillation counting, and by radon de-emanation from the sample into a Lucas Cell chamber for counting. These two methods are described in the report "Two Test Procedures for Radon in Drinking Water, Interlaboratory Collaborative Study" (EPA, 1987e). EPA has slightly modified the liquid scintillation procedure described in that report and proposes to establish this revised method as EPA Method 913.

In direct, low volume liquid scintillation measurement of radon, a small volume of water (about 10 ml) is placed in a vial with a scintillation solution (mineral oil), mixed, and the vial placed in a liquid scintillation counter. Counting time can range up to 100 minutes or more, depending on the amount of radon in the sample and the desired precision of analysis. Companies using liquid scintillation counting report that they can analyze 50–200 samples daily (EPA, 1989e; 1990j).

In using the Lucas Cell method, radon-free helium or aged air (to allow the radon present to decay out) is bubbled through a water sample in a bubbling apparatus into an evacuated scintillation chamber. After equilibrium is reached (3 to 4 hours), this chamber is placed in a counter and the scintillations are counted through its window. This method generally allows measurement of lower level of radon than does low volume direct liquid scintillation. However, this is a method that is difficult to use, requiring specialized, glassware and skilled technicians. Most laboratories that currently measure radon use liquid scintillation, and few have the equipment to perform Lucas Cell counting. Estimated start-up cost to obtain Lucas Cell equipment would be about \$35,000 (to do 30–40 samples daily), plus technician training (EPA, 1989d). Also, a variant of the Lucas Cell method, requiring the same equipment and skills, can be used to measure radium 226 (because radon 222 is the first daughter of radium 226). The widespread use of Lucas Cells for radon analysis would make the method less available for radium 226 analyses. These factors limit use of the Lucas Cell method on a large scale for radon measurement, and EPA believes it is not appropriate as the sole basis for compliance monitoring for radon in water. EPA includes it here as an adjunct to the liquid scintillation method; the Lucas Cell method would be allowed to be used for radon measurement, but could not be relied on to support a national sampling program

for radon in water. EPA believes only liquid scintillation would allow accurate analysis of the large number of samples required nation wide by these proposed regulations.

iii. *Radium.* Several methods are available for the specific analysis of radium 226 and 228 as listed in table 15. Most of the methods in the interim regulations for radium analyses are technique dependent and time-intensive. Some of the other methods listed appear to be improvements over the existing approved methods. For example, co-precipitation steps are employed in methods for both radium 226 and 228 to purify the sample and reduce interferences.

Analysis of radium 226 by radon emanation requires allowing the radium 226 to decay to radon (to equilibrium) in the water sample, bubbling radon-free helium gas through the water into an evacuated Lucas Cell counting chamber, and then counting the chamber. While this method can produce good precision and accuracy at relatively low radium 226 levels, it is as noted above, time consuming and requires special equipment and specially trained lab technicians. These factors may limit its use on a large scale. EPA believes this is, however, one of several appropriate methods for radium 226. Appropriately conducted gross alpha screens should eliminate the need for specific radium 226 analyses in many cases.

iv. *Uranium.* Uranium can be analyzed using fluorometric (mass) or radiochemical methods, or using alpha

spectrometry. The fluorometric method measures the mass of total uranium present in the sample. Because EPA is proposing an MCL expressed in mass units, this is the preferred method.

However, should the final MCL be an activity standard, the results of fluorometric analysis may be converted to an activity level using the conversion factor 1.3 pCi/ μ g. This conversion factor is based on evaluation of the relative occurrence of the different radioisotopes of uranium in water samples. This value is somewhat different from uranium naturally occurring in soil, which has an estimated conversion factor of 0.68 pCi/ μ g. The need for conversion from mass to activity following analysis, and the potential for variability in the conversion factor would be a weakness of the fluorometric method in determining compliance with an activity MCL for uranium. EPA solicits public comment on the advisability of continuing to allow use of this method to measure uranium activity levels.

The radiochemical method for uranium involves chemical separation of uranium followed by counting in an alpha counter, as described below. Uranium is specifically precipitated from the sample and the sample is then counted. In addition, uranium may be measured by alpha spectrometry which allows for the determination of individual isotopes of uranium and the calculation of the total mass of uranium present. These aforementioned methods may be found to be more expensive to perform than the fluorometric method,

however EPA believes that the results will be more reliable.

c. *Sample Collection, handling and preservation.* In order to ensure that samples arriving at laboratories for analysis are in good condition, EPA is proposing requirements for sample collection, handling and preservation, as described in table 16. For radium, uranium and gross alpha and gross beta analysis, sample collection should be performed as for inorganic contaminant monitoring as described in EPA's "Manual for the Certification of Laboratories Analyzing Drinking Water" (EPA, 1990b).

For radon, because it is a volatile gas, special attention to sample collection is required. Either the VOC sample collection method, or one of the methods described in "Two Test Procedures for Radon in Drinking Water, Interlaboratory Collaborative Study" (EPA, 1987e) should be used. In addition, because plastics can absorb radon, glass bottles with teflon lined caps must be used. Finally, EPA's assessment of laboratory performance is premised on analysis of samples no longer than 4 days after collection. Laboratories unable to comply with this holding time maximum may have difficulty performing within the estimated precision and accuracy bounds. EPA solicits public comment on the proposed sample collection procedures for radon in drinking water, including any available data on radon loss from water samples during collection by different methods.

TABLE 16.—SAMPLING HANDLING, PRESERVATION, HOLDING TIMES

Parameter	Preservative ¹	Contained ²	Maximum holding time ³
Gross alpha.....	Conc. HCl or HNO ₃ to pH <2 ⁴	P or G.....	6 months.
Gross beta.....	Conc. HCl or HNO ₃ to pH <2 ⁴	P or G.....	6 months.
Radium-226.....	Conc. HCl or HNO ₃ to pH <2.....	P or G.....	6 months.
Radium-228.....	Conc. HCl or HNO ₃ to pH <2.....	P or G.....	6 months.
Radium-222 ⁵	Cool 4° C.....	Glass with Teflon-lined septum.....	4 days.
Uranium natural.....	Conc. HCl or HNO ₃ to pH <2.....	P or G.....	6 months.
Radioactive Cesium.....	Conc. HCl to pH <2.....	P or G.....	6 months.
Radioactive Strontium.....	Conc. HCl or HNO ₃ to pH <2.....	P or G.....	6 months.
Radioactive Iodine.....	None.....	P or G.....	6 months.
Tritium.....	None.....	Glass.....	6 months.
Photon emitters.....	Conc. HCl or HNO ₃ to pH <2.....	P or G.....	6 months.

¹ (All except radon-222 samples). It is recommended that the preservative be added to the sample at the time of collection unless suspended solids activity is to be measured. However, if the sample must be shipped to a laboratory or storage area, acidification of the sample (in its original container) may be delayed for a period not to exceed 5 days. A minimum of 16 hours must elapse between acidification and analysis.

² P = Plastic, hard or soft; G = Glass, hard or soft.

³ Holding time is defined as the period from time of sampling to time of analysis. In all cases, samples should be analyzed as soon after collection as possible.

⁴ If HCl is used to acidify samples which are to be analyzed for gross alpha or gross beta activities, the acid salts must be converted to nitrate salts before transfer of the samples to planchets.

⁵ The procedure of a positive pressure collection in 60-ml glass bottles is to be followed. This procedure is described in appendix C, NIRS Sampling Instructions—Radon, p. 26, Two Test Procedures For Radon In Drinking Water, Interlaboratory Collaborative Study, (EPA, 1978e).

2. *Cost of performing analyses.* The actual costs of performing analysis may vary with laboratory, analytical technique selected, the total number of

samples analyzed by a lab, and by other factors. Table 17 lists the approximate costs for analyses of drinking water samples for radionuclides. These cost

data, recently assembled, are preliminary and may be different in practice for the following reasons: (a) For some analytes, few commercial

laboratories exist to help define costs; (b) as the number of experienced laboratories increases, the costs can be expected to decrease; (c) analytical costs are determined, to some extent, by the quality control efforts and quality assurance programs adhered to by the analytical laboratory; (d) per-sample costs are influenced by the number of samples analyzed per unit time. EPA solicits comments on its cost estimates from laboratories experienced in performing these analyses.

TABLE 17.—ESTIMATED COST OF ANALYSES FOR RADIONUCLIDES

Radionuclides	Approximate cost for analysis in drinking water
Radium-226	\$85
Radium-228	100
Uranium (total)	45
U isotopic	125
Radon-222	50
Gross alpha emitters	35
Gross beta emitters	35
Radioactive Cesium	100
Radioactive Iodine	100
Radioactive Strontium	105
Total, 89 and 90	
Tritium	50
Gamma emitters	110

Source: (EPA, 1991m)

Note: Estimated costs are on a per-sample basis; analysis of multiple samples may have lower cost.

3. *Method detection limits and practical quantitation levels.* Method detection limits (MDLs) and practical quantitation levels (PQLs) are two performance measures used by EPA to estimate the limits of performance of analytic chemistry methods for measuring contaminants in drinking water. An MDL is the lowest level of a contaminant that can be measured by a specific method under ideal research conditions. A PQL is the level at which a contaminant can be ascertained with specified methods on a routine basis, (such as compliance monitoring) by well managed laboratories, and within specified precision and accuracy limits. The proposed PQLs for the radionuclides are listed in Table 18 below (EPA, 1991r).

EPA considers PQLs in evaluating alternatives for the MCL. Consideration of the PQL is especially important for those contaminants for which EPA is proposing MCLGs at zero. The feasibility of implementing an MCL at a particular level is in part determined by the ability of analytical methods to ascertain contaminant levels with sufficient precision and accuracy at or near the MCL.

EPA usually defines the method detection limit (MDL) as the minimum concentration of a substance that can be measured and reported with 99 percent confidence that the true value is greater than zero. The term MDL is used interchangeably with minimum detectable activity (MDA) in radionuclide analysis, and is defined as that amount of activity which in the same counting time, gives a count which is different from the background count by three times the standard deviation of the background count. Identifying an MDL concentration is limited by the fact that MDLs (MDAs) are specific to the performance of a given measurement system, and vary from system to system.

The concept of MDL is different for radionuclide measurement than for non-radioactive chemicals. Because counting times can be expanded to days or even weeks or longer in a research setting, very small differences from background can theoretically be detected depending on research needs. These extremely long counting times are unrealistic for compliance monitoring for drinking water. EPA has sometimes set laboratory performance expectations at a level 5 to 10 times the MDL. However, MDLs (MDAs) are not necessarily reproducible on a routine basis in a given laboratory, even when the same analytical procedures, instrumentation and sample matrix are used. EPA has therefore relied on actual performance data generated in Performance Evaluation and other studies in setting standards for laboratory performance for radionuclide monitoring.

The PQL is determined through evaluation of the results of interlaboratory studies, such as performance evaluation (PE) studies. In these studies, prepared samples of known concentration are distributed for analysis to participating labs as unknowns. The results of the analyses by the participants are compared with the known value and with each other to estimate the precision and accuracy of both the methods used and the lab's proficiency in using the method. (See 54 FR 220624, May 22, 1989; 52 FR 25699, July 8, 1987; and 50 FR 46906, November 13, 1985 for further discussions on MDLs and the concept of PQLs.) MDLs (MDA) are lower than PQLs since the MDL represents the lowest level at which there is 99% confidence that the true value is greater than zero, while the PQL represents the level that can be ascertained under practical and routine laboratory conditions. The measurement of radioactivity becomes limited at low concentrations and small sample sizes due to the random nature of radioactive

decay and the resulting theoretical counting uncertainty. The counting uncertainty is the major contribution to the overall uncertainty. This uncertainty must be calculated and added to the result and other uncertainties to determine whether or not the analysis has demonstrated compliance (EPA, 1991r; 1986a).

The method for estimating the PQLs for radionuclides is based on the same criteria as that used for organic and inorganic compounds and incorporates, through the methodology, the counting time and background activity in each laboratory. The PQLs for radionuclides are estimated based on results from EPA's Water Supply Performance Evaluation and Intercomparison Cross Check Studies for radionuclides with the exception of radon, for which no PE or cross check data were available. These studies are conducted as a part of EPA's laboratory certification program by EPA's Environmental Measurement Systems Laboratory in Las Vegas. A number of laboratories, ranging from 60 to 140 depending on the analyte, have participated annually and biannually, respectively, in the PE and cross check studies. There are approximately one hundred certified laboratories nationally that have the capability to conduct analyses for the radionuclides currently regulated (Ra-226 and 228, gross α and gross β , and also uranium). PE studies were used to estimate PQLs primarily because they are good indicators of laboratory performance. The fact that they are blind samples eliminates possible biases. The intercomparison studies cross check study data served as an alternative source of data as well as a means of verifying laboratory performance.

Because until recently there was not a standardized analytic method, nor a calibration standard for radon, no PE studies were done on radon. Both a standard method and calibration standard have now been developed and EPA plans to include radon in future PE studies. In the interim, EPA relied on two data sources for estimating performance of the available radon methods. One study was the report "Two Test Procedures for Radon in Drinking Water, Interlaboratory Collaborative Study" (EPA, 1987e), which evaluated performance of the radon methods down to 1600 pCi/l. Because EPA wanted to consider MCL alternatives lower than this, additional data on radon measurement was generated by EPA. Radon samples, supported by radium 226 bound to a resin, as low as 100 pCi/l were tested by 12 labs using liquid scintillation and 4

labs using Lucas Cells, and these data were used to evaluate performance of the methods and estimate the PQL (EPA, 1991n; 1991r). EPA considers the radon data to be a limited basis for deriving a PQL, and solicits additional information on radon analysis.

The PQLs for the radionuclides were derived applying a procedure described in 50 FR 46908, Nov. 13, 1985 and 54 FR 22100, May 22, 1989. Data from all reporting laboratories of Performance Evaluations A and B, 1983-1990 (EPA, 1991r), which include EPA and State laboratories, were used for radium, uranium, gross alpha and gross beta. For radon, data from the two studies described above were used. The PQL procedure generates acceptance limits that are set around a "true" value. Using the procedure described in these notices, the PQLs for all radionuclide contaminants were set at a concentration where it was estimated that at least 75 percent of all reporting laboratories are within the specified acceptance ranges.

The radon PQL required some special considerations. Because of the practical considerations involved in analyzing a radioisotope with a short half life (3.8 days), EPA has made allowance for transport time from the water supply to the laboratory in setting the PQL. EPA has premised its PQL on samples being analyzed no longer than 4 days after collection; mail delays could reduce accuracy for low level samples. The sample collection date and time would be required on all samples collected, and will be used by the laboratory in calculating radon levels present at the time of collection. This assumption, along with the fact that the radon PQL was based on more limited data than the other radionuclides PQLs makes it more uncertain than the other PQL values. If the PQL were premised on an 8 day time frame from collection to analysis (to make greater allowance for mail delays or back-ups in laboratories), the PQL could be 500 pCi/l. Similarly, if the counting time were increased (beyond the proposed 100 minutes), a value somewhat lower than 300 pCi/l might be achievable as the PQL. Similarly, should 100 minute counts prove infeasible, a higher PQL may need to be set. EPA solicits public comment on these issues related to the radon PQL.

Different PQL values could also be established using different acceptance limits. At an acceptance limit of $\pm 20\%$, for example, the radon PQL would be about 500 pCi/l; at acceptance limits of $\pm 40\%$ the PQL would be 200 pCi/l. In choosing an acceptance limit of $\pm 30\%$

and PQL of 300 pCi/l, EPA considered the likely reliability of the overall compliance monitoring program, the number of systems that would have measurements within the error range, and the risks of radon. With an error band of $\pm 40\%$, and a PQL of 200 pCi/l, approximately 19,000 of the estimated 33,000 systems affected would fall within the error band and would have potentially unclear compliance status, potentially resulting in requests for re-testing and additional burdens on states to determine and achieve compliance. When EPA chose a $\pm 40\%$ acceptance limit for the vinyl chloride regulation, only a few hundred systems were expected to exceed the MCL; care could be taken to accurately determine compliance status if it were in doubt. With a $\pm 30\%$ error band for radon at 300 pCi/l, only 5000 to 7000 systems would have potentially unclear compliance status because of data uncertainty. While this number would decrease with an even narrower error band, the individual lifetime risks would be higher. Therefore, on balance, EPA is proposing to set the PQL at 300 pCi/l.

EPA recognizes that some laboratories may be able to achieve better performance than $\pm 30\%$ at 300 pCi/l. Lowry (1991) very recently published a study indicating that radon could be measured using liquid scintillation counting at 300 pCi/l with an overall error of less than $\pm 10\%$, assuming 4 days from sample collection to analysis. EPA is reviewing this study to identify potential improvements in its own procedures for measuring radon by LSC. However, EPA does not now believe most laboratories will be capable of the levels of precision and accuracy achieved by Lowry. EPA will soon conduct a series of performance evaluation studies on radon analysis to better gauge performance levels and to develop a data set on which to base lab certification determinations when the regulations are final. In addition, Vitz (1991) recently published a paper evaluating the effect of several different variables on error in measurements, including the effect of the type of scintillation cocktail used, the type of vials and standardization procedure used, and temperature control and instrument settings. Vitz also commented on sampling procedures. Vitz (1991) overall reported that radon levels of 200 pCi/l may be measured with 20% precision using a 20 minute count, if all parameters are optimized. EPA is reviewing this report to identify improvements in its proposed radon method, EPA Method 913.

EPA solicits public comment on these issues, and will continue to collect and evaluate additional data to refine and better substantiate the proposed PQL and the constraints on regulation imposed by limits on analytic methods. EPA specifically requests comment on information supporting PQLs higher than the proposed PQL (such as 500 pCi/l), and information supporting a lower PQL than that proposed, such as 200 pCi/l.

Public comments are requested on the approach used to determine the PQLs for radionuclide contaminants, on the proposed PQLs for these contaminants, and information is sought on any new developments in methodology for the radionuclide contaminants that may be used to support development of these regulations. EPA also solicits public comment on the usefulness of PQLs in setting standards, and the appropriateness of alternative methods for accounting for analytic methods limitations in setting standards.

TABLE 18.—PRACTICAL QUANTITATION LEVELS (PQLs) FOR RADIONUCLIDE CONTAMINANTS

Contaminant	PQL (pCi/l)
Radium-226	5
Radium-228	5
Uranium natural	5
Radon-222	300
Gross alpha emitters	15
Gross beta emitters	30
Radioactive Cesium:	
134	10
137	10
Radioactive Iodine	20
Radioactive Strontium:	
89	5
90	5
Tritium	1200

(EPA, 1991r)

E. Laboratory Approval and Certification

1. *Background.* The ultimate effectiveness of the proposed regulations depends upon the ability of laboratories to reliably analyze contaminants at relatively low levels. The existing drinking water laboratory certification program (LCP) established by EPA requires that only certified laboratories may analyze compliance samples.

External checks of performance to evaluate a laboratory's ability to analyze samples for regulated contaminants within specific limits is the primary means of judging lab performance and determining whether to grant certification. EPA provides performance evaluation samples to laboratories on a regular basis;

participation in the PE program is prerequisite for a laboratory to achieve certification and to remain certified for analyzing drinking water compliance samples. Achieving acceptable performance in these studies of known test samples provides some indication that the laboratory is following proper practices. Unacceptable performance may be indicative of problems that could affect the reliability of the compliance monitoring data.

Unacceptable performance on PE studies should trigger an investigation to establish the possible cause(s) and to take corrective action. EPA recognizes that even superior analytical laboratories occasionally produce data which are outside the acceptance limits due to statistical reasons rather than from any actual analytical problems. EPA has incorporated the criteria of using fixed acceptance limits around the true value to overcome this misinterpretation of analytical results. A provision for rapid follow-up analysis is necessary if a laboratory fails the initial determination to decrease the likelihood of statistical error and to determine if a real problem exists.

EPA's present PE sample program and the approaches to determine laboratory performance requirements were discussed in 50 FR 46907 (November 13, 1985). In addition, guidance of minimum quality assurance requirements, conditions of laboratory inspections and other elements of laboratory certification requirements for laboratories conducting compliance monitoring measurements are detailed in the Manual for the Certification of Laboratories Analyzing Drinking Water, Criteria and Procedures Quality Assurance (EPA, 1990b). Participation by 300 or more laboratories in the interlaboratory studies required in the LCP demonstrates that laboratory capability and capacity for the radionuclide analyses necessary to support this proposed regulation exists.

Acceptable performance has historically been identified by EPA using one of two different approaches: (1) Regressions from performance of preselected laboratories (using 95 percent confidence limits), or (2) specified accuracy requirements. Acceptance limits based on specified accuracy requirements are developed from existing PE study data. EPA was able to use fixed acceptance limits for all of the contaminants proposed in today's rule because of the availability of PE data, with the exception of radon in which an interlaboratory collaborative study was used. EPA would prefer to use the true value

approach because it is the better indicator of performance and provides laboratories with a fixed target. This approach requires that each laboratory demonstrate its ability to perform within pre-defined limits. Laboratory performance is evaluated using a constant yardstick independent of performance achieved by other laboratories participating in the same study. A fixed criterion based on a percent error around the "true" value reflects the experience obtained from numerous laboratories and includes relationships of the accuracy and precision of the measurement to the concentration of the analyte. It also assumes little or no bias in the analytical methods that may result in average reporting values different from the reference "true" value. This concept assures that reported results can be related to the percentage of variance from the PQL.

2. *Acceptance limits for radionuclide contaminants.* EPA relied on the data generated from the radon interlaboratory collaborative study to estimate acceptance limits (using the approach described in 54 FR 22131-22132, May 22, 1989). The levels (100, 200, and 500 pCi/l in lab samples, corresponding to 200, 400 and 1000 pCi/l in field samples analyzed 4 days after collection) used in the study were below and above the PQL (300 pCi/l) proposed in this regulation, demonstrating the participating laboratory's ability to measure at or around the proposed MCL (EPA, 1991r).

Performance data are available for all of the other radionuclide contaminants at the levels proposed for regulation (EPA, 1991r). The acceptance limits are developed using the approach noted above, resulting in the specification of a "plus or minus percent of true value" for setting acceptance limits. The available PE data indicate that both the precision and accuracy attained for specific radionuclide contaminants are contaminant specific. The "plus or minus percent of the true value" acceptance limits have been derived for each contaminant taking into consideration past performance of the laboratories and the expected precision and accuracy (EPA, 1991r).

EPA believes that the nature of radionuclides analysis (i.e., background counts, counting time, decay) requires unique analytical considerations. In some cases this may result in a greater effort from laboratories to perform analyses which meet the proposed acceptance limits. The Agency believes that these circumstances are to be addressed by the individual

laboratories, when executing the analyses using the proposed methodology.

The proposed acceptance limits for the radionuclide contaminants are summarized in Table 19. The acceptance limits only apply to concentrations above the PQL.

TABLE 19.—PROPOSED ACCEPTANCE LIMITS

Contaminant	Acceptance limits at the PQL (percent)
Radium-226.....	±30
Radium-228.....	±50
Uranium natural.....	±30
Radon-222.....	1 ±30
Gross alpha emitters.....	±50
Gross beta emitters.....	±30
Radioactive Cesium:	
134.....	±20
137.....	±30
Radioactive Iodine.....	±20
Radioactive Strontium:	
89.....	±50
90.....	±30
Tritium.....	±20

¹ Acceptance limits based on 100 minute count (EPA, 1991r)

F. Proposed MCLs and Alternatives Considered

The sections below discuss derivation of each of the MCLs for the contaminants proposed for regulation. The first section presents an evaluation of radon in water and discusses special policy issues EPA considered in choosing the MCL to propose for radon. This is followed by the derivation of MCLs for radium, and uranium which are proposed today. This is followed by an alternative basis for regulation, the lowest technically feasible levels limited by affordability to large water suppliers, on which EPA requests public comment. Finally, proposed MCLs for alpha and beta emitters are discussed.

1. *Radon.* Regulation of radon in water is a complex issue for several reasons. In evaluating the various alternatives for proposing a radon MCL, EPA considered the critical policy question of whether radon in water should be regulated like other drinking water contaminants, or whether it should be regulated more in accord with its importance compared to overall radon exposures. In considering the radon MCL, EPA reviewed and evaluated alternatives over the range of 200 to 2000 pCi/l.

The primary health hazard posed by radon in water is due to its volatilization from water during household water use, and enrichment of indoor air radon levels, thereby contributing to increased

risk of lung cancer. Direct ingestion of radon may also pose some risk of stomach and other cancers. While on average water makes a small contribution to indoor air radon (about 5% for houses served by ground water), it is prevalent in drinking water from groundwater wells and does contribute to the very substantial risks posed by radon in the environment overall. Because it is a volatile gas, very little radon is expected to be found in surface water, and no surface water systems are anticipated to require treatment. EPA estimates that 30,000 or more public water systems serving 30 million or more people may have radon in water at levels exceeding an estimated 1×10^{-4} risk level (150 pCi/l water).

Outdoor background levels of radon in air (about 0.1 to 0.5 pCi/l air) present estimated lifetime lung cancer risks of about 1 in 1000, a risk level above those generally accepted in EPA regulatory programs. Typical indoor air radon levels (1–2 pCi/l air) pose estimated lifetime lung cancer risks near 1 in 100. Radon is estimated to cause 8000 to 40,000 (EPA, 1989g) lung cancer deaths annually, of which about 75–400 may be attributed to radon from drinking water. As discussed in Section IV.C.2 above, the SAB/RAC is presently reviewing a proposed revision of the radon risk estimate, which could result in an approximate 30% reduction in these estimates. While the average water contribution to indoor air radon is small relative to the contribution of soil gas (for most houses), it does represent a substantial estimated number of annual cancer cases and in many communities poses individual lifetime risks above EPA's lifetime cancer risk goal for drinking water regulations of 10^{-4} to 10^{-6} (52 FR 25698, July 8, 1987). While these risk estimates have inherent uncertainties, they are no greater here than for other contaminants regulated by EPA using such a risk assessment approach.

A number of factors were considered in deciding on the approach to regulating radon. Radon in public water systems can be treated centrally rather than on a house-by-house basis as is the case with radon from soil gas. Radon can be removed from drinking water efficiently and relatively inexpensively (compared with other drinking water contaminants and treatments), although costs to small systems will be high. Also, while EPA has no authority to regulate radon in private homes (or wells), the Agency is required to regulate water delivered to customers by public water systems under the SDWA. Moreover, the 1986 amendments

to the SDWA require EPA to develop an MCL for radon.

Finally, while saving an estimated 57–100 cancer cases annually (the estimated benefit of regulating radon in water in the range of 500 to 200 pCi/l, respectively) is a small number compared with the estimated 8,000–40,000 annual cancer cases caused by radon exposure (EPA, 1989g), it would be a substantial public health benefit compared with other drinking water regulations and other environmental regulation programs administered by EPA. For example, regulation of vinyl chloride in drinking water is estimated to avoid 27 cancer cases annually; the only other currently regulated individual contaminant (out of some 50 standards) with more estimated cancer risk avoided is ethylene dibromide, with an estimated 72 cases avoided per year. EPA concluded that regulation of radon in water constitutes an opportunity to achieve a substantial public health benefit in an area of high environmental risk, and to do so at relatively low cost.

EPA also considered other factors in developing its proposed radon MCL, including the ability to accurately measure radon in water and potential implementation difficulties. As discussed in Sections V.D and E, radon poses some challenges in routine measurement. Not only is it a volatile gas, it also has a short radioactive half-life (3.8 days). This means that samples must be carefully collected and promptly sent for analysis; analytic sensitivity decreases by one half for every 3.8 days after collection that the sample is analyzed. While the count time could in theory be extended to compensate for this, the 300 pCi/l PQL is premised on a count of 100 minutes, which EPA believes is at a reasonable limit, and that overall, a PQL of 300 pCi/l is at the reasonable limit of the analytic methods, based on available data. Should additional data show that it is difficult for labs to perform consistent analysis at this level with the expected precision (due perhaps to long transport times), or if data uncertainty near this value (i.e. the $\pm 30\%$ now estimated and believed to be acceptable) renders the MCL impossible to implement, the PQL could possibly be reviewed and revised upward. Similarly, should new data show analysis easier at low levels than now believed, the PQL could be revised downward. The recent study by Lowry (1991) indicates that some individual labs may achieve better performance than the minimum requirements proposed here.

EPA also considered potential difficulties in implementing a radon

MCL at different levels in the range of 200 to 2000 pCi/l. Implementation was considered to be a serious issue only in the range of 200–500 pCi/l. A large number of PWS would be affected at any MCL in the range of 200 to 500 pCi/l, but many more systems would be affected at the 200 pCi/l MCL option. There are approximately 48,000 community and 20,000 non-community, non-transient public water systems served by ground water sources. At an MCL of 200 pCi/l, EPA estimates that 33,000 PWSs would be required to take action to meet the MCL; at 300 pCi/l, 26,000 systems would be affected; at 500 pCi/l, approximately 18,000 systems would be affected. EPA is particularly concerned about these impacts because of the overall regulatory burden being placed on water suppliers as the 83 mandated contaminants are regulated. For example, 40,000 systems are expected to need to treat to meet the recently promulgated lead and copper regulations. EPA solicits public comment on consideration of implementation issues in setting MCLs.

Because radon is a problem only for ground water dependent systems, a large percentage of the affected systems are small (85% serve fewer than 500 people). While treatment for radon is inexpensive for larger PWSs (on a per-house basis), smaller systems will have more difficulty installing treatment. Also, exemptions are unlikely to be available to these systems, as all of the options considered are in the 10^{-4} risk range, which is the proposed limit for identifying unreasonable risks to health (URTH) posed by drinking water contamination in the draft document: "Guidance for Developing Health Criteria for Determining Unreasonable Risks to Health" (EPA, 1990k). EPA also recognizes that there would be a substantial State burden to implement any radon MCL in the 200 to 500 pCi/l range, but that it would be greater at the lower MCL option. EPA solicits public comment on how these considerations should be factored into establishing the radon MCL.

EPA considered proposing radon MCLs in the range of 200 to 2000 pCi/l. However, 2000 pCi/l represents an estimated 10^{-3} risk, and this alternative was rejected as inconsistent with the SDWA and Agency risk management policy. EPA therefore concentrated much of its effort on evaluating MCL alternatives in the range of 200 to 500 pCi/l. Based on considerations of available treatment technologies, cost, risk, analytic capabilities and implementation concerns, EPA determined that 300 pCi/l is the lowest

feasible level at which radon can be regulated, and proposes to set the MCL at this level.

EPA solicits public comment on this proposal, as well as all the alternatives considered, from 200 to 2000 pCi/l. In particular, comment is sought on 200 pCi/l as an alternative, in light of new studies indicating that radon analysis may be improved in the future and the greater health benefits at this level (an estimated 20 additional cancer cases avoided annually), and also on 500 pCi/l as an alternative, if analytic difficulties in a implementation setting become apparent (i.e., the PQL may be set higher if 4 day delivery to labs proves too short) and in light of the substantial implementation burden that would be imposed by lower values.

Another issue of concern to EPA regarding radon regulation was application of the MCL to private wells. The relative magnitude of risks from radon in water (vs soil gas) is important for home owners to bear in mind when applying any radon MCL to private wells. Because the soil gas contribution to indoor radon levels is in most cases much larger than the water contribution, testing and mitigation strategies for private homes should consider all sources of radon. The mitigation strategy which is most cost-effective overall for an individual home should be used. In a majority of cases, this will mean controlling the soil gas contribution to indoor radon before ensuring that the radon MCL is met. Soil gas contributes more radon to the indoor air than does water in most houses. Economies of scale for treatment by public water systems make radon removal from water cost-effective for PWSs. Water treatment is unlikely to be the most cost-effective first step in mitigating radon in individual homes (relative to soil gas mitigation). EPA has prepared several publications for homeowners and private well owners to help them in addressing their radon problems effectively and for the lowest cost possible. These publications include, for general information on radon risks, testing in the home, and mitigation of soil gas contributions to indoor air, A Citizen's Guide to Radon and A Homeowners Guide to Radon; and for radon in water, Radionuclides in Drinking Water Fact Sheet. These materials can be requested from either the Safe Drinking Water Hotline, at 1-800-426-4791, or from the radon information hotline, at 1-800-SOS-RADON.

EPA solicits public comment on these issues regarding regulation of radon under the SDWA.

2. Radium and Uranium MCLs. As described above, all radionuclides cause cancer by the same mechanism, i.e., delivery of ionizing radiation to tissues (in the case of drinking water, internally), and it is therefore possible to make comparisons among them. Several comparisons may be made in the course of developing regulatory standards including the total radioactivity removed from potable water in pCi/l or more conveniently, uCi/l (one million pCi equals one uCi), the pCi/l (or uCi/l) removed, or rem/s, the effective dose to tissue. These comparisons allow assessment of the relative cost-effectiveness of controlling the different radionuclides subject to today's rule.

The control options considered by EPA for radium and uranium range from the contaminant level that can be reliably measured in routine laboratory operations (PQL) to the level representing an approximate 10^{-4} individual lifetime risk level, and for uranium, the level at which kidney toxicity concern arises. EPA also considered the levels to which these contaminants can be treated in drinking water in assessing which control options are technically feasible.

The Agency determined that it is technically feasible to achieve control levels of 5 pCi/l for radium 226, radium 228 and uranium. EPA then considered a number of cost factors related to the removal of these contaminants. The high cost of removing radium and uranium as compared with radon was especially apparent when the cost per uCi removed from water was estimated. Radon removal cost approximately \$20,000 per uCi removed, whereas radium and uranium at the lowest technically feasible levels cost from \$2 million to \$5 million per uCi removed. Even at radium levels equal to the 10^{-4} risk level, the removal cost per uCi was \$600,000 to \$1 million per uCi (EPA, 1991i). For uranium at the kidney toxicity limit of 20 $\mu\text{g/l}$ (representing a cancer risk of approximately 10^{-5}), the removal cost was nearly \$2 million per uCi. EPA also reviewed the cost per rem removal for these contaminants. While the cost differences are less dramatic, they are still large, and in the same direction i.e., the cost per rem of removing radium and uranium is far greater than the cost of removing radon.

In assessing the MCL alternatives, EPA also considered the chemical toxicity of uranium to the kidneys. While the 10^{-4} risk level is 170 pCi/l, adverse effects on the kidneys may occur at lower levels for naturally occurring uranium in the environment. EPA estimates that the DWEL for

uranium is 100 $\mu\text{g/l}$, and using a 20% RSC, as discussed in section IV above, a safe drinking water level would be 20 $\mu\text{g/l}$, corresponding to approximately 26 pCi/l (using the conversion of 1.3 pCi/ μg ; this value rounds to 30 pCi/l). This value is below the 10^{-4} lifetime individual cancer risk level and is protective for kidney toxicity, the limiting adverse health effect level for naturally occurring uranium in drinking water.

The SDWA directs EPA to consider cost in setting MCLs. The Agency does not believe it would be reasonable to establish MCLs that would impose such disproportionate costs for removing what is effectively the same contaminant from drinking water. Therefore, EPA proposes to set MCLs for radium 226 and radium 228 and uranium at levels less stringent than may be technically feasible (if only affordability to large systems was taken into consideration). These levels are, for radium 226, 20 pCi/l, for radium 228, 20 pCi/l, and for uranium, 20 $\mu\text{g/l}$. The proposed levels will assure that persons served by PWS will not be exposed to greater than 10^{-4} lifetime cancer risk, and will for uranium also protect against possible kidney toxicity.

Table 21 compares some of the important considerations in establishing standards that are cost-effective with the same considerations at the lowest technically feasible level.

EPA recognizes that setting radium standards at levels less stringent than the interim standards may be disruptive to some state regulatory programs. The interim standard for radium is 5 pCi/l for radium 226 and 228 combined. Primacy states have been implementing and enforcing this MCL since it was effective in 1976, with mixed results. A large percentage of water systems with radium problems have chronically exceeded the radium MCL, and continue to do so. States have been working to bring these systems into compliance, and some may view a revision of the radium MCLs to 20 pCi/l for radium 226 and 20 pCi/l for radium 228 as frustrating their program planning and expectations. EPA understands these concerns and has considered them in its deliberations. The Agency believes however, that it is appropriate to revise these MCLs in light of the fact that the cost of removing radionuclides from drinking water by removing uranium and radium to the technologically feasible limit is disproportionate to the cost of removing radon.

EPA solicits public comment on this approach to setting MCLs, and on the MCL levels proposed. EPA also solicits

comments from systems that have installed or need to install treatment to meet the current interim standards.

3. *Alternative MCLs.* EPA has generally set MCLs at the lowest technically achievable level, with cost considered largely in terms of whether the standards would be affordable to large public water systems.

Key technical information used in assessing the lowest feasible levels has been based on engineering and analytic chemistry capabilities, with affordability determinations based on the estimated increase in residential water bills.

Engineering feasibility is assessed based on the treatments available as BAT, and the occurrence of the regulated contaminants. The BAT treatments for these contaminants are, at maximum efficiency, capable of achieving 90% and greater removals for all of the regulated contaminants. Radon removal by aeration treatment can exceed 99% removal. Occurrence of the contaminants is reviewed in detail in

section III of this notice. The average radon level in the NIRS survey was about 800 pCi/l, with a maximum of 26,000 pCi/l. Maximum radium 226 and 228 levels in the NIRS survey were both below 20 pCi/l (occurrence at higher levels is based on a statistical projection of the 1900 data points in NIRS to the entire country). The maximum uranium level in NIRS was 88 pCi/l. Based on treatability and occurrence, radon could theoretically be treated to 100 pCi/l or lower in most water supply systems, radium 226 and 228 could be treated to 2 pCi/l or lower in most water supplies, and uranium could be treated to 5 pCi/l or lower as described in Table 20.

In reviewing analytic capabilities, EPA identifies the practical quantitation level, or PQL. This is the level EPA believes can be measured on a routine basis in compliance monitoring, within a fixed error rate (often $\pm 20\%$ – 40%), as described in section V.E. In reviewing the analytic capabilities, EPA determined that the radon PQL could be

established at 300 pCi/l, and that radium 226, radium 228, and uranium PQLs can be set at 5 pCi/l.

The cost of treatment for removal of these contaminants ranges from about \$4 per household per year (for radon) to \$60 per household per year for radium. These are costs to large public water systems serving 50,000 to 75,000, and cost to residents of small systems would be higher. All of these costs are within the range that EPA considers to be affordable for large public water supply systems.

Based on these considerations, EPA would consider the lowest feasible levels to which these contaminants could be regulated are 300 pCi/l for radon, 5 pCi/l for radium 226, 5 pCi/l for radium 228, and 5 pCi/l for uranium (kidney toxicity by uranium is not the limiting factor here, as it is above) and 15 pCi/l for adjusted gross alpha. EPA solicits public comment on these levels as possible alternative MCLs for the radionuclides.

TABLE 20.—BACKGROUND INFORMATION ON RADIONUCLIDES

	Rn-222	Ra-226	Ra-228	U	Alpha
Lowest Treatment level (pCi/l).....	<100	<2	<2	<5	<5
PQL (pCi/l).....	300	5	5	5	15
Treatment Cost \$/HH/yr.—Large systems.....	\$4	\$60	\$60	\$20	\$130
1×10^{-4} Lifetime risk level (pCi/l).....	150	22	26	170	n/a
Pop exposed $> 10^{-4}$ Lifetime Risk (pre-regulation).....	27M	890K	100K	50K	n/a
Estimated drinking water cases/yr. (pre-regulation).....	195	8	2.1	1.6	n/a

Source: EPA 1991i

TABLE 21.—COMPARISON OF PROPOSED AND LOWEST FEASIBLE MCL OPTIONS

	Rn-222	Ra-226	Ra-228	U	Alpha
MCL Options (pCi/l):					
Proposed	300	20	20	20 $\mu\text{g/l}$	15
Alternate	300	5	5	5	15
Lifetime risk:					
Proposed	2×10^{-4}	1×10^{-4}	8×10^{-5}	1×10^{-5}	n/a
Alternate	2×10^{-4}	2×10^{-5}	2×10^{-5}	3×10^{-6}	n/a
Cases avoided/yr.:					
Proposed	80	3	0.2	0.2 ¹	n/a
Alternate	80	5	0.6	0.6	n/a
Fraction of total cases avoided/yr.:					
Proposed	0.41	0.38	0.03	0.17	n/a
Alternate	0.41	0.63	0.19	0.33	n/a
No. Sys affected:					
Proposed	26,000	70	40	1500	130
Alternate	26,000	590	500	7200	130
Total \$/yr.:					
Proposed	\$180M	\$30M	\$6M	\$55M	\$37M
Alternate	\$180M	\$120M	\$55M	\$225M	\$37M
\$/rem(K):					
Proposed	\$1K	\$1.6K	\$3.9K	\$380K	n/a
Alternate	\$1K	\$5K	\$17K	\$700K	n/a
\$/uCi:					
Proposed	\$20K	\$600K	\$1.6M	\$2M	n/a
Alternate	\$20K	\$2M	\$2M	\$4M	n/a
Incr. \$/case:					
Proposed	\$2.9M	\$23M	\$50M	\$57M	n/a
Alternate	\$2.9M	\$75M	\$158M	—	n/a

Source: EPA 1991i

¹ Approximately 900,000 people also reduced to exposure level with increased probability of kidney toxicity.

4. *Gross alpha and beta and photon MCLs.* Alpha and beta emitters are a way of broadly grouping a large number of radioactive contaminants based on their radioactive characteristics. Radioactive isotopes have characteristic decay patterns which allow them to be identified as being primarily alpha, beta or photon (gamma ray) emitters (although many compounds decay by a combination of these routes with one being predominant). Alpha emitters are primarily naturally occurring compounds, although some are man-made (such as plutonium). Beta emitters are mostly man-made compounds, but some are naturally occurring (such as radium 226 and lead 210). The 1986 amendments to the SDWA direct EPA to establish MCLs for these two categories of radioactive contaminants (section 1412(b)(1)).

Because they emit ionizing radiation as they decay, they are all considered to be group A human carcinogens, and the proposed MCLG for both alpha and beta/photon emitters is zero, as described in Section IV-C above.

The other radionuclides proposed for regulation today all fall into one of these categories (radium 226, radon and uranium are alpha emitters, and radium 228 is a beta emitter). EPA has proposed to set individual MCLs for radon, radium and uranium because they occur in the water of an important number of public water supplies over substantial parts of the country. This is not true for the majority of radionuclides. Many of the other alpha and beta emitters have never been detected in drinking water, and others only sporadically. Many of the naturally occurring radionuclides may be found in water because they are radioactive progeny of the more commonly occurring radionuclides for which individual MCLs are being proposed. The man-made radionuclides may be found in water as a result of their release from facilities where they are produced, stored, used or disposed of. These could include nuclear power plants, research or manufacturing facilities, high or low level radioactive waste disposal sites, and others.

There are approximately 2000 nuclides that fall into these categories. Many of these have very short half-lives, and are not of concern in water; several hundred have longer half lives and could be important. EPA is proposing to regulate these contaminants as classes of compounds because they all cause cancer by the same basic mechanism. Also, EPA believes that none of them individually occur with enough frequency to warrant a national regulation, but that as groups they are

found frequently enough to warrant public health concern, and therefore regulation. EPA further believes that public water systems using water that is known to have the potential to become contaminated with nuclear reactor (or other nuclear facility) releases, by either scheduled or unscheduled release, should monitor for these compounds and that there should be standards in place to protect the public should high levels occur.

a. *Gross alpha.* There is currently an interim MCL for alpha emitters which was set as a screen for the occurrence of both radium 226 and other alpha emitting radionuclides that might be present in drinking water. Few water systems have ever exceeded the gross alpha MCL (except when it is due to high radium levels). The 15 pCi/l MCL was intended to limit overall exposure to alpha radiation in drinking water, and EPA continues to believe that it is important to limit overall alpha emitter exposure. EPA is proposing to retain but modify the gross alpha MCL. As discussed in Section IV-C, alpha emitters are carcinogenic, and EPA is proposing to set the MCLG for gross alpha at zero, in accord with EPA's general policy for regulating carcinogens occurring in drinking water.

Most alpha emitters in drinking water occur naturally. Alpha emitters other than radium and uranium that have been found in drinking water include polonium and thorium as discussed in section III-F above. In addition, plutonium and americium may occur. EPA believes the potential for occurrence of these contaminants indicates that a screening standard would be appropriate to restrict the limited exposure that may occur, while not requiring that separate MCLs, with required separate monitoring, be set. The available data indicate that occurrence of alpha emitters other than those specifically regulated (i.e. radon, radium and uranium) is infrequent. EPA believes this limited occurrence means that individual, nationally applicable MCLs are not warranted, but that some mechanism to detect potential occurrence and reduce exposure when alpha emitters do occur is warranted. EPA believes that a gross alpha MCL would provide a mechanism to detect and reduce exposure to alpha emitters, while not overburdening water systems with monitoring requirements.

EPA has reviewed the risks for these contaminants, and discusses them in Section IV-C above and in greater detail in the alpha emitter criteria document. As noted above, the MCLG for alpha emitters is being proposed as zero,

because all ionizing radiation is considered to be carcinogenic. Lifetime risks in the 1×10^{-4} range for alpha emitters in drinking water are 14 pCi/l for polonium, 50-125 pCi/l for various thorium isotopes, and 7 pCi/l for plutonium (see appendix C).

EPA has also reviewed the available treatment information to determine what levels of alpha emitters can be successfully removed. EPA has also conducted limited pilot scale studies to better determine the treatability of polonium (EPA, 1991k). BAT has been identified as reverse osmosis. Ion exchange, GAC, and coagulation and filtration have been shown to remove some of these contaminants, but data are inadequate to consider any of them BAT. RO can remove up to 99% of alpha emitters that may be present in drinking water.

The analytic methods for measuring alpha emitters is the gross alpha test (EPA No.900.0) or gross alpha by coprecipitation, when high amounts of solids are present. As discussed in section V.D, the PQL for gross alpha is 15 pCi/l, with $\pm 40\%$ error.

While retaining the gross alpha MCL, EPA proposes to revise its approach to this standard. Because separate MCLs are being proposed for radium and uranium, the gross alpha MCL will not include them (the current gross alpha standard includes radium 226 but excludes uranium and radon). The alpha emitter MCL will be defined as gross alpha, less radium 226, and uranium (and not including radon). To avoid confusion of the regulatory use of the term "gross alpha" and the laboratory measurement that is called gross alpha, EPA proposes to designate the MCL as "adjusted gross alpha", to indicate that compliance with the gross alpha MCL would be determined by first measuring gross alpha and if the value exceeds the MCL, measuring and subtracting out the radium 226 and uranium contributions (because of the way the test is conducted, any radon initially present in a sample would be driven off by the sample preparation; therefore, while the adjusted gross alpha measure does not include radon, neither would radon be subtracted from the gross alpha measurement, as would radium 226 and uranium). EPA proposes that the "adjusted gross alpha" MCL would be gross alpha minus radium 226 and minus uranium, and proposes that the adjusted gross alpha MCL be set at 15 pCi/l. This MCL would, overall, limit exposure to other radionuclides and ensure that risks from alpha emitting radionuclides would not exceed the 10^{-4} to 10^{-6} lifetime risk range. EPA considers this to

be the lowest level at which it is feasible to set the adjusted gross alpha MCL, bounded by 10^{-4} lifetime risk.

EPA recognizes that there could be situations in which several radionuclides occur together in drinking water. Based on the data available today, it appears unlikely that radionuclides will co-occur at levels near the proposed MCLs. Therefore, the potential for overall risks to be greater than 10^{-4} appears small. EPA solicits public comment on its proposed MCLs in regard to possible co-occurrence of radionuclides and possible approaches to ensuring that overall risks do not rise above the 10^{-4} level.

Assessing the impacts of the proposed adjusted gross alpha MCL is difficult due to uncertainties in the available data, and also because of its "screening" nature. As a worst case, EPA estimates that up to 130 systems could exceed an adjusted gross alpha MCL of 15 pCi/l, and believes the actual number of systems would be far below that number. No violators of the current gross alpha MCL have been identified in a search of the EPA compliance data base.

b. Beta and photon emitters. There are over 200 beta and photon emitters covered by this regulation (see appendix B). Most of these are man-made isotopes and are the waste from nuclear power plants, medical industry, nuclear weapon development, and other industries. The Agency regulated the beta and photon emitters as a class in the NIPDWRs with an MCL of 4 mrem per year effective dose equivalent (whole body or any organ), and proposes to retain the interim standard as a final MCL.

Strontium-90, strontium-89, cesium-134, cesium-137, iodine-131, and cobalt-60 are the beta emitters with the highest toxicity. These are also the most likely to be found in reactor releases or accidents.

Ion exchange and reverse osmosis are capable of removing up to 99% of these isotopes, with several exceptions. Only reverse osmosis is capable of removing iodine. Also, while there is no treatment for tritium other than use of an alternate water source, EPA considers an alternate water source (including bottled water) to be BAT for this limited purpose. Both ion exchange and reverse osmosis may be used to remove mixed commercial radionuclides. The treatment cost varies between \$330 to \$540 per household per year for a small system and between \$84 to \$230 per household per year for a large system.

Beta emitters are measured by the gross beta method (EPA No. 900.0), which has PQL of 30 pCi/l.

At the time of the interim standards, there was great concern about the fallout of strontium 90 (and others) from above-ground nuclear tests. Since the ban on above-ground tests in 1963, environmental levels have declined and the concern now has shifted more toward water which is vulnerable to radionuclides released from industrial and governmental (DOE) facilities and, to a lesser degree, landfills. Controls are in place for discharges from these sources under the Clean Water Act, RCRA, and NRC and DOE regulations. These regulations are intended to be protective of the environment and public health. The drinking water standard under these conditions becomes an adjunct to these release restrictions, and establishes values which would be used in case of an accident or unscheduled release, where these regulations are violated. EPA nonetheless believes it is necessary and appropriate to establish the beta and photon emitter MCL to ensure protection of public health in these circumstances, and is required to set such a standard by the 1986 amendment to the SDWA, which listed beta emitters as among the 83 contaminants for which MCLs must be developed.

The Agency is proposing to set the beta MCL at 4 mrem ede per year. The individual lifetime risk at 4 mrem ede/year is estimated to be approximately 1×10^{-4} .

One naturally occurring beta emitter of potential concern is lead-210. Lead-210 is the first long lived progeny of radon-222, and could be anticipated to co-occur in ground water where radon occurs. However, there are few data on lead-210 occurrence in water, and modeling exercises of lead movement through the environment indicate that low levels (mass) of lead may bind to soils and be unavailable to water (EPA, 1986e). Because data on which to base risk and regulatory impact estimates are lacking, EPA is proposing to require unregulated contaminant monitoring for lead-210, as discussed below, and consider it for possible regulation in the future.

G. Proposed Monitoring and Reporting Requirements

Compliance monitoring requirements are being proposed for determining compliance with the MCLs. In developing the proposed compliance monitoring requirements for these contaminants, EPA considered:

- (1) The likely source of contamination of drinking water,
- (2) The differences between ground water and surface water systems,

(3) The collection of samples which are representative of consumer exposure,

(4) The economic burden of sample collection and analysis,

(5) The use of historical monitoring data to identify vulnerable systems and to specify monitoring requirements for each of the individual systems,

(6) The limited occurrence of some contaminants, and

(7) The need for States to tailor monitoring requirements to site-specific conditions.

A major goal has been to make these monitoring requirements consistent with the monitoring requirements for other regulated drinking water contaminants, as described in the standardized monitoring requirements. EPA wants to develop monitoring requirements that will meet the statutory goal of ensuring compliance with the MCLs while providing efficient utilization of State and utility resources. The monitoring program will focus on targeting the monitoring efforts in individual water supply systems to the contaminants that are likely to be present. The general approach taken by EPA includes:

- Providing latitude to the States to target monitoring efforts based on vulnerability of the system to a particular contaminant if its occurrence is not widespread and thus avoiding unnecessary monitoring efforts.
- Allowing the use of recent monitoring data in lieu of new data if the system has conducted a monitoring program using reliable analytical methods.
- Allowing the use of historical monitoring data meeting specified quality requirements and other available records to make decisions regarding the vulnerability of a system to contamination.
- Requiring all vulnerable systems to conduct repeat monitoring unless the system demonstrates that its vulnerability status has changed.
- Designating sampling locations and frequencies that permit simultaneous monitoring for all regulated contaminants, whenever possible and advantageous.
- Requiring that samples be taken during high vulnerability times.

EPA is proposing to require monitoring to begin at the start of the next 3 year period after the regulation is effective, which is January 1, 1996, in accord with the standardized monitoring requirements. However, under Section 1445, monitoring, reporting, and recordkeeping regulations which may be used to assist in determining compliance may be made effective on the date that

the regulation is finalized. EPA solicits public comment on the effective date for the monitoring requirements, particularly whether monitoring should begin before January 1, 1996.

Surface water systems must sample at points in the distribution system which are representative of each source i.e., at each entry point to the distribution system which is located after any treatment and which is representative of each source. The number of samples will be determined by the number of sources or treatment plants. Sampling must be done at entry points to the distribution system for ground water systems and the number of samples will be determined by the number of entry points. This approach will make it easier to identify possible contaminated sources (wells) within a system. In both surface and ground water systems, the proposed sampling locations are such that the same sampling locations may be used for the collection of samples for other source-related contaminants such as the volatile organic chemicals and inorganic chemicals, which simplifies sample collection efforts.

Because of the large number of regulations for drinking water contaminants that have been developed in recent years, EPA recently sought to coordinate contaminant monitoring to simplify the requirements imposed on public water systems. This coordination is called the standardized monitoring framework. EPA announced this framework in January of 1991 (56 FR 3526-3597, January 30, 1991), and held a public meeting to discuss the concept and solicit public comment. Reaction of the water supply industry was generally favorable, and EPA has proceeded to implement the standardized monitoring framework in the context of individual rulemakings (56 FR 3526, January 30, 1991). The monitoring requirements for the radionuclides regulations will rely on the basic structure described in the documents on standardized monitoring. Initial monitoring will begin with the compliance period that begins January 1, 1996, and would be required to be completed by January 1, 1999. EPA solicits public comment on the use of the Standardized Monitoring scheme for the radionuclides regulations.

The monitoring requirements for the different radionuclides would vary depending on their likely occurrence. For example for radon, all ground water systems would be required to collect one sample from each entry point to the distribution system quarterly at first and annually after compliance is established, whereas surface water

systems are not required to test for radon.

Only systems designated as vulnerable would be required to monitor gross beta for beta and photon emitters. Vulnerability for beta and photon emitters would be determined by states, and would be based on the proximity of the system to potential sources of man-made radionuclides, such as nuclear power facilities, universities or other research facilities, or manufacturing facilities that use radioactive material, or radioactive waste disposal sites (for either high or low level waste). EPA suggests a 15 mile radius around such facilities as the vulnerable area for purposes of requiring gross beta monitoring.

MCL exceedences would trigger increased monitoring requirements, which could be reduced to the base monitoring requirements once compliance with the MCL is re-established.

Because these contaminants present risks from long-term, chronic exposure, only community and non-community, non-transient public water supplies would be required to monitor for them.

1. *Radon.*—a. *Radon monitoring for surface water supplied systems.* Systems relying exclusively on surface water as their water source would not be required to sample for radon. Systems that rely in part on ground water would be considered groundwater systems for purposes of radon monitoring. Systems that use ground water to supplement surface water during low-flow periods would be required to monitor finished water at each entry point to the distribution system for radon during periods of ground water use, according to the groundwater monitoring requirements. Also, groundwater under the influence of surface water would be considered ground water for this regulation.

b. *Radon monitoring for ground water systems.* Systems relying wholly or in part on ground water would be required to sample for radon quarterly for one year at each well or entry point to the distribution system. If the average of all first year samples at each well is below the MCL, monitoring would be reduced to one sample annually per well or entry point to the distribution system. All samples would be required to be of finished water, as it enters the distribution system and after any treatment.

c. *Radon compliance and increased and decreased monitoring requirements.* Compliance would be determined based on an average of 4 quarterly samples in the initial year of monitoring, and

annual samples in the second and third years of the first compliance period. The reported values (rather than the bottom of the error band associated with the measurements) would be averaged together; systems with averages exceeding 300 pCi/l at any well or sampling point would be deemed to be out of compliance. Systems exceeding the MCL would be required to monitor quarterly until the average of 4 consecutive samples are less than the MCL. Systems would then be allowed to reduce monitoring to one sample annually per well or sampling point. States would be allowed to reduce monitoring requirements to one sample per three-year compliance period per well or sampling point, if the state determines that the system is reliably and consistently below the MCL. Systems monitoring annually or once per three year compliance period that exceed the radon MCL in a single sample would be required to revert to quarterly monitoring until the average of 4 consecutive samples is less than the MCL. Ground water systems with unconnected wells would be required to conduct increased monitoring only at those wells exceeding the MCL.

EPA is proposing more frequent monitoring for radon than for the other radionuclides because levels are known to vary diurnally and over the course of a year. Variability may be 100% or more. EPA solicits public comment on the proposed radon monitoring requirements, and on the advisability of allowing up to nine years between samples, and the criteria that might be used to identify systems very unlikely to exceed the MCL for which monitoring once every nine years may be adequate.

2. *Gross Alpha, Radium-226 and Uranium.* All ground water and surface water systems would be required to monitor annually for gross alpha, and if the gross alpha measurement exceeds the MCL for radium 226 and/or uranium, specific analyses for the contaminant(s) exceeding the MCL would be required. Systems would be required to sample each well or entry point to the distribution system. Samples would be of finished water after any treatment. Systems exceeding the MCL would be required to monitor quarterly until four consecutive samples were less than the MCL. For systems not exceeding the MCL after three consecutive annual samples are taken, sampling would be reduced to one sample per three year compliance period. States would be allowed to reduce monitoring to once per nine year compliance cycle if the state determines that a system consistently and reliably meets the

MCL. Systems with unconnected wells would be required to conduct increased monitoring only at those wells exceeding the MCL.

Gross alpha measurement would be used both to determine compliance with the adjusted gross alpha MCL and as a screen for radium 226 and uranium, provided the analytic requirements described in section V.D are met. These requirements include appropriate calibration of equipment to ensure that neither radium 226 or uranium are underestimated by the screen. Compliance determinations for adjusted gross alpha, radium 226 and uranium based on gross alpha measurements are listed in Figure 2. Adjusted gross alpha is defined as the gross alpha measurement less radium 226 and less uranium. Because the adjusted gross alpha MCL is less than the radium 226 and uranium MCLs, one or both of these may need to be specifically analyzed to determine adjusted gross alpha compliance even though the gross alpha screen indicates that both the radium 226 and uranium MCLs have been met (i.e., if the gross alpha is between 15 and 20 pCi/l).

Systems with gross alpha less than the radium 226 or uranium MCLs would be considered to be in compliance with those respective MCLs. Specific analyses of either or both contaminants would be required if the gross alpha measurement exceeds the respective MCL.

For adjusted gross alpha, radium 226 and uranium, compliance would be based on the average of an initial sample exceeding the MCL and a confirmation sample (as the reported values, not the lower bound of the error band associated with the measurement).

EPA solicits public comment on the proposed radium 226 and uranium monitoring, and use of the gross alpha screen for these contaminants, especially in light of the fact that the uranium MCL is proposed to be set based on mass rather than activity measurements.

3. *Radium-228.* All ground water and surface water systems would be required to monitor annually for radium 228. Systems would be required to sample each well or entry point to the distribution system. Samples would be of finished water after any treatment. Systems exceeding the MCL would be required to monitor quarterly until four consecutive samples were less than the MCL. For systems not exceeding the MCL, sampling would be reduced to one sample per three year compliance period after three consecutive annual samples are below the MCL. States would be allowed to reduce monitoring to one

sample per nine year compliance cycle if the state determines that a system consistently and reliably meets the MCL. Systems with unconnected wells would be required to conduct increased monitoring only at those wells exceeding the MCL.

Gross beta measurement would be allowed to serve as a screen for radium 228 levels. Systems with gross beta levels less than the radium 228 MCL would be considered to be in compliance with the radium-228 MCL. Systems with gross beta levels exceeding the radium-228 MCL would be required to measure radium-228 specifically.

For radium-228, compliance would be based on the average of an initial sample exceeding the MCL and a confirmation sample (as the reported values, not the lower bound of the error band associated with the measurement).

4. *Beta and photon emitters.* Because of revisions in the estimated drinking water concentrations of various beta and photon emitters that correspond to a yearly dose of 4 mrem ede, EPA is proposing to revise and simplify the monitoring requirements for beta and photon emitters. The revised estimates in general allow for less specific monitoring and greater reliance on the gross beta screen. In addition, because of the special vulnerability circumstances which could result in the presence of man-made beta emitters in drinking water, monitoring more frequent than that required for other contaminants under the standardized monitoring program is being proposed.

The current gross beta monitoring program requires all vulnerable PWS and all systems serving 100,000 or more persons to perform a screen plus specific analyses for several contaminants. EPA proposes to revise these requirements so that only vulnerable systems would be required to perform gross beta monitoring. States would make the vulnerability determination for each PWS, and it would be based on the proximity of the water source for the system to facilities using or producing radioactive materials. EPA suggests that all systems within a 15 mile radius of these facilities be considered vulnerable, as well as systems using a water source clearly influenced by such a facility. All systems using water that could be influenced by releases (either scheduled or unscheduled) from facilities such as nuclear power plants, Department of Energy nuclear facilities, Nuclear Regulatory Commission licensees, low or high level nuclear waste storage or disposal facilities, or other facilities using or making radioactive material should be

considered vulnerable. Monitoring could be required of either surface or ground water dependent systems, depending on their vulnerability.

EPA considered two gross beta monitoring programs. Under the first alternative, the current 50 pCi/l screen for presumptive compliance, along with additional specific monitoring for tritium and strontium 90 would be required. If the 50 pCi/l screen were met, and tritium and strontium were individually and combined below the 4 mrem ede value, the system would be considered to be in compliance. The beta screen would be required quarterly and the tritium and strontium would be required annually, as described in Figure 3. Under the second alternative, the beta screen would be set at the gross beta PQL of 30 pCi/l, and only specific analysis of tritium would be required. The screen would be required quarterly and the tritium analysis annually. Because of the vulnerable status of these systems, no reduced monitoring would be allowed. Under either alternative, water suppliers would be required to identify the particular contaminants present if the screen is exceeded, and add the estimated doses including tritium and strontium 90 under the first alternative to ensure that the 4 mrem ede MCL is not exceeded. The values in Appendix B would be used to perform this calculation. EPA believes that either of these monitoring plans would ensure the safety the public served by vulnerable water supplies.

EPA proposes to establish the first alternative, of retaining the 50 pCi/l screen for presumptive compliance with the gross beta MCL and specific analyses for tritium and strontium 90 (because 50 pCi/l would not adequately screen for tritium and Sr-90 at the 4 mrem ede level). EPA solicits public comment on reducing the screen to 30 pCi/l and eliminating the strontium 90 measurement.

5. *Monitoring schedule.* In order to moderate demand on analytic laboratories, the monitoring requirements for determining compliance with these regulations would be phased-in over a 3 year period. States would determine the schedule for phasing in monitoring, but all systems would be required to have performed their first year of sampling by the end of the first 3 year compliance period (i.e., December 31, 1998).

6. *Grandfathering data.* Interim MCLs have been in place and analytic methods available for radium, gross alpha and beta and photon emitters since 1976. Validated analytic methods for other radionuclides, including

uranium, have also been available since then. Most water supply systems that would be covered by these proposed regulations have been monitoring for the regulated contaminants for several years. Data collected in compliance with the interim MCL requirements (i.e., analyses by certified laboratories) would be allowed to be used to determine compliance with the proposed MCLs. While no EPA-approved radon analytic method has been available, EPA recognizes that many water supplies have conducted some radon monitoring in recent years. Data on radon occurrence generated using

methods and with laboratory performance similar to those proposed here would be allowed to be used to determine compliance, at the discretion of the State.

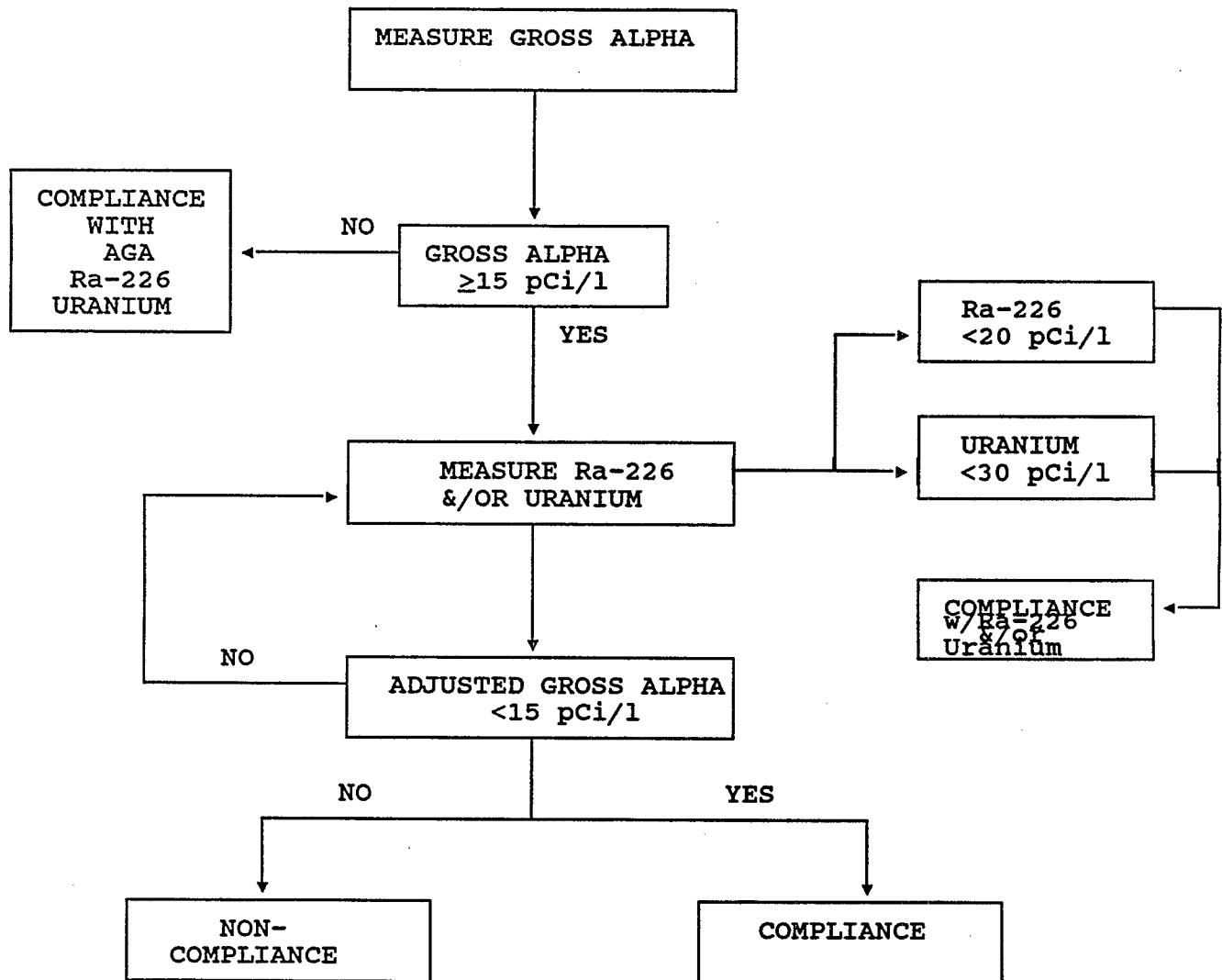
7. Monitoring for unregulated contaminants. As discussed above, available data are inadequate to determine whether lead-210 occurs frequently enough to warrant public health concern. EPA is therefore proposing to require all community and non-community, non-transient public water systems to collect one sample from each well or entry point to the distribution system, after any treatment,

and analyze the sample for lead-210. States may require systems to collect one confirmation sample. All regulated systems would be required to collect and analyze one sample for lead-210, so that adequate data on which to assess exposure may be obtained. EPA solicits public comment on this proposed monitoring for unregulated contaminants.

EPA solicits public comment on the proposed monitoring requirements described above.

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FIGURE 2. GROSS ALPHA SCREENING

AGA= Adjusted Gross Alpha

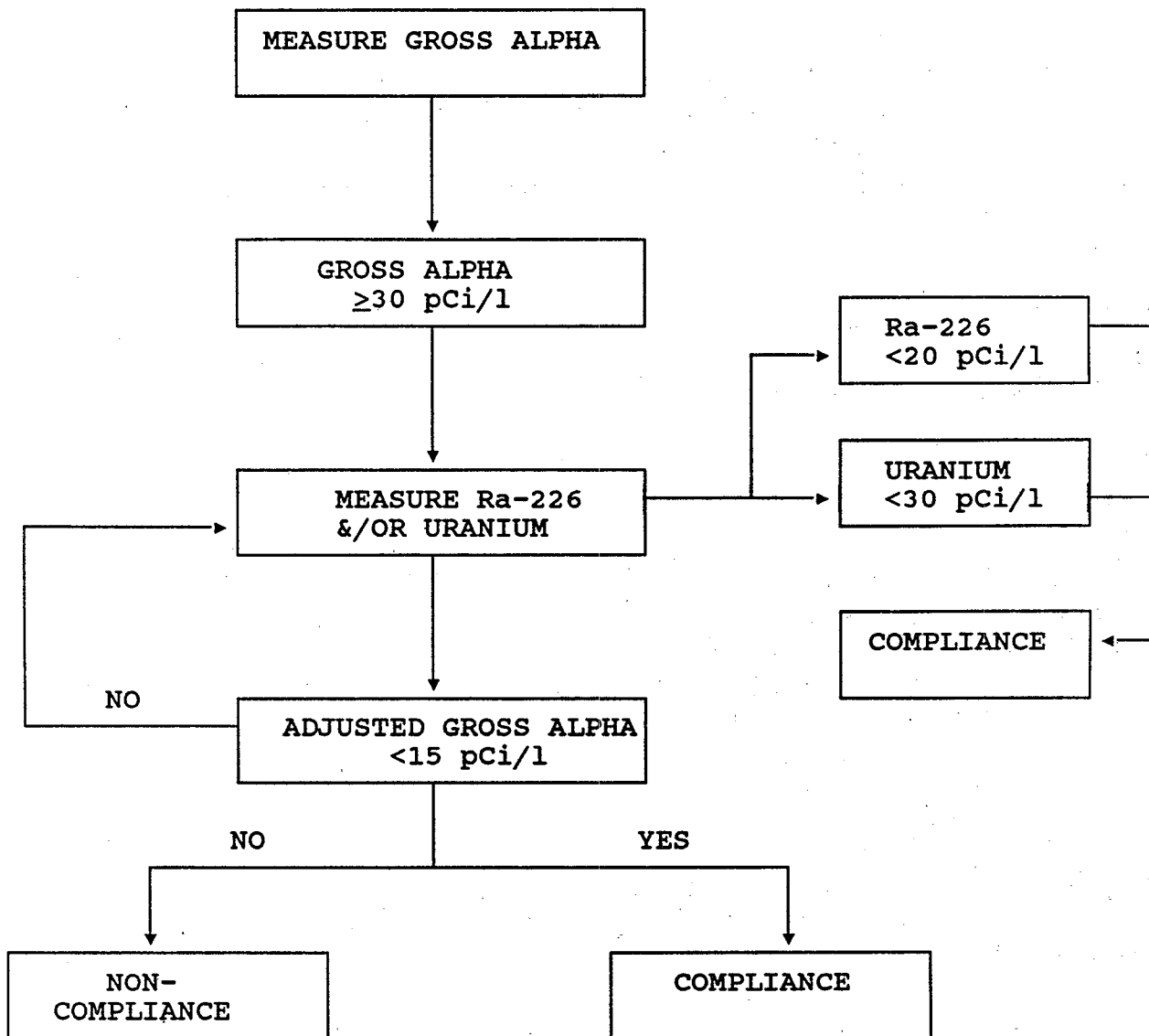
FIGURE 2. GROSS ALPHA SCREENING (Continued)

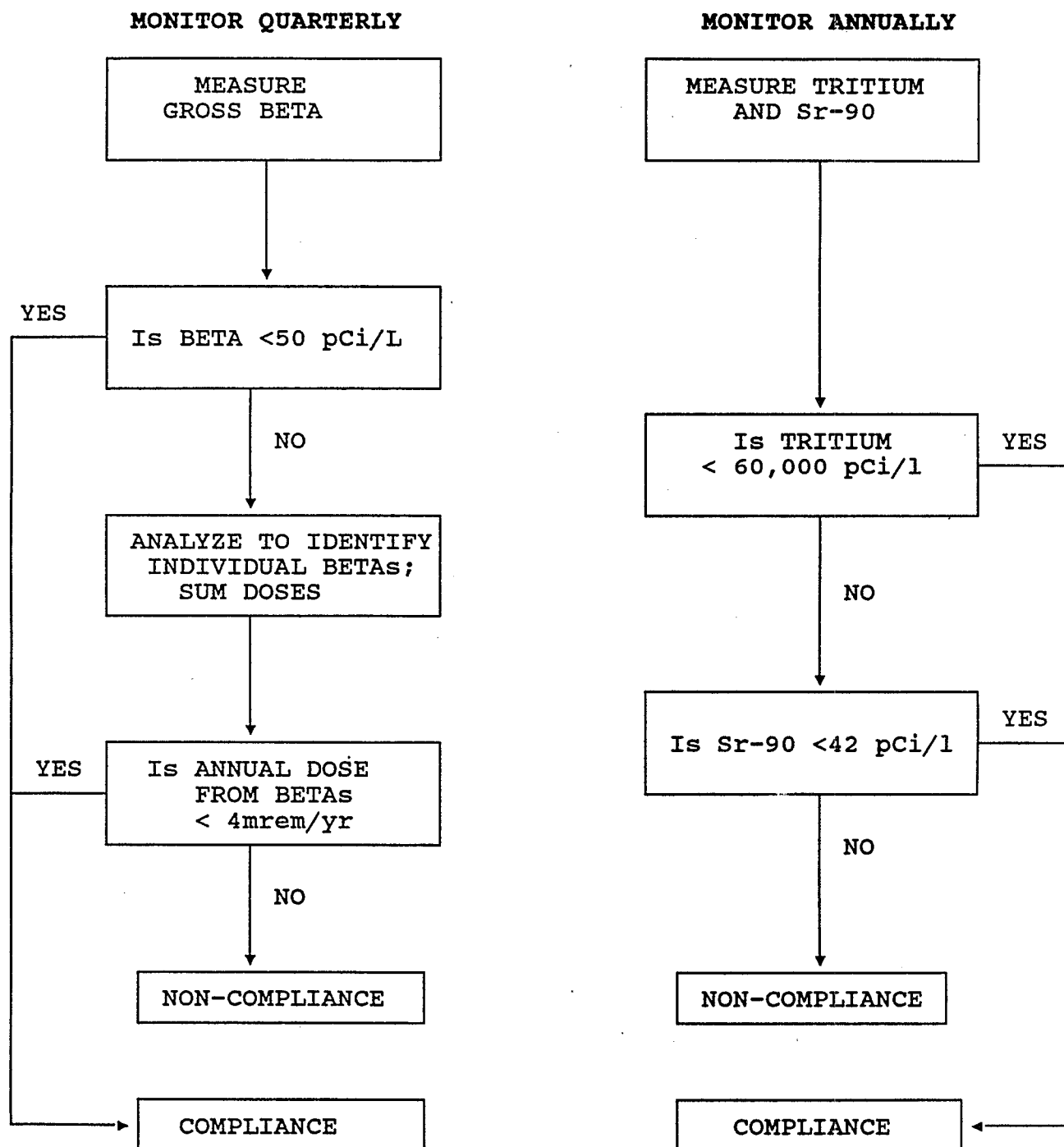
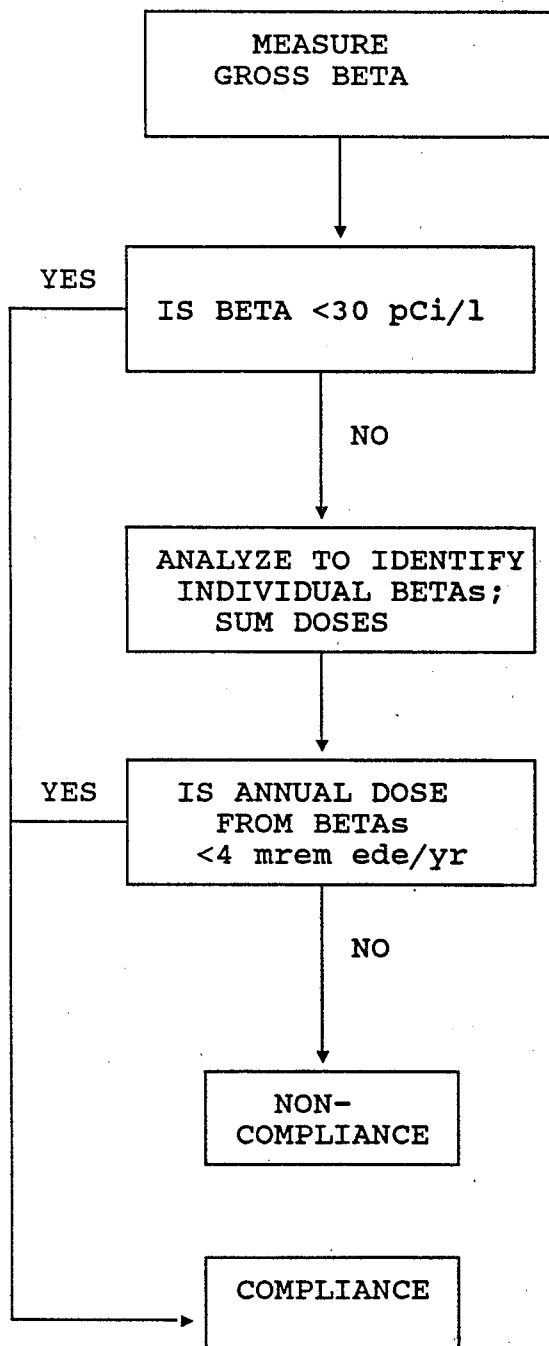
FIGURE 3. GROSS BETA SCREENING OPTIONSOption 1: Higher Screening Level

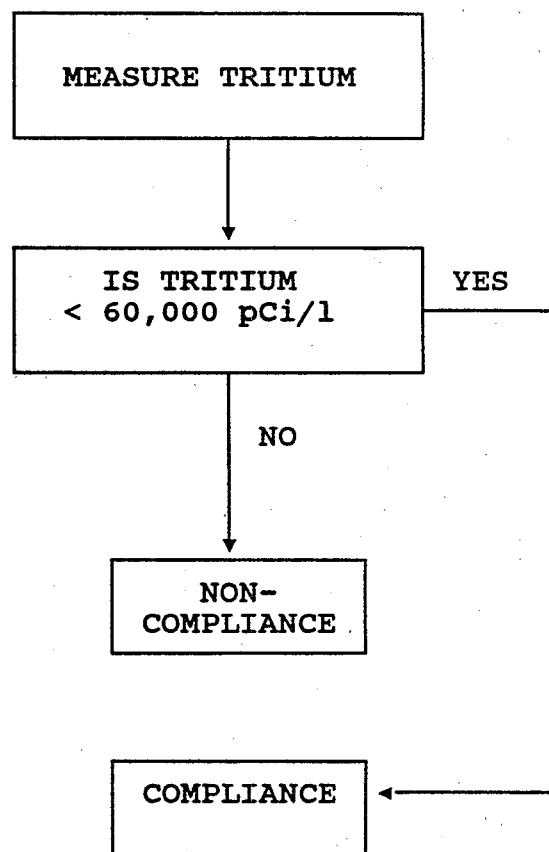
FIGURE 3. GROSS BETA SCREENING OPTIONS (Continued)

Option 2: Low Screening Level

MONITOR QUARTERLY



MONITOR ANNUALLY



H. State Implementation

The Safe Drinking Water Act provides that States may assume primary implementation and enforcement responsibilities. Fifty-four out of 57 jurisdictions have applied for and received primary enforcement responsibility (primacy) under the Act. To implement the Federal regulations for drinking water contaminants, States must adopt their own regulations which are at least as stringent as the Federal regulations. This section of today's proposal describes the regulations and other procedures/policies that States must adopt to implement today's proposed rule. EPA has recently revised its program implementation requirements of 40 CFR part 142, on December 20, 1989 (54 FR 52126), and on June 3, 1991 (56 FR 25046).

To implement today's proposed rule, States will be required to adopt the following regulatory requirements: When they are promulgated: § 141.25, Radionuclide Sampling and Analytical Requirements; § 141.32, General public notice requirements; § 141.44, Special monitoring for radionuclides; and § 141.64, MCLs for Radionuclides.

In addition to adopting drinking water regulations no less stringent than the Federal regulations listed above, EPA is proposing that States adopt certain requirements related to this regulation in order to have their program revision application approved by EPA. In various respects the proposed NPDWRs provide flexibility to the State with regard to implementation of the monitoring requirements by this rule.

Today EPA is also proposing changes to State recordkeeping and reporting requirements. EPA's proposed changes are discussed below. EPA requests comments on these proposed requirements.

1. *Special primacy requirements.* To ensure that the State program includes all the elements necessary for an effective and enforceable program, the State's request for approval must contain the following:

(1) If the State issues waivers, the procedures and/or policies the State will use to conduct and/or evaluate vulnerability assessments;

(2) The procedures/policies the State will use to allow a system to decrease its monitoring frequency; and

(3) A plan that ensures that each system monitors by the end of each compliance period.

2. *State recordkeeping.* The current regulations in § 142.14 require States with primary enforcement responsibility to keep records of analytical results to

determine compliance, system inventories, sanitary surveys, State approvals, enforcement actions, and the issuance of variances and exemptions. In this rule, States would be required to keep additional records of the following: (1) Any determination of a system's vulnerability to contamination by beta and photon emitters due to proximity of an emitting source; and (2) any determination that a system can reduce monitoring for gross beta, uranium, radium 226 or 228 or increase monitoring frequency. The records must include the basis for the decision, and the repeat monitoring frequency.

Systems that are located within a 15 mile radius of a nuclear facility, or hospitals or other locations that use, store or dispose of radioactive material should be considered vulnerable to contamination, and therefore, monitored more closely. Systems that are found not to be vulnerable to contamination will be listed as such. This information will be available to EPA for review in a similar manner to current records kept by the State.

3. *State reporting.* EPA currently requires in § 141.15 that States report to EPA information such as violations, variances and exemption status, enforcement actions, etc. EPA proposes in this notice that in addition to the current reporting requirements, States report to EPA:

(1) A list of all systems on which the State conducted a vulnerability assessment, the dates of those assessments, the results of that assessment, and the basis for that determination; and

(2) A list of all systems on which the State is requiring repeat monitoring for Gross beta particle and photon emitters, the results of that assessment, and the basis for that determination.

EPA believes that the State reporting requirements contained in this proposal are necessary to ensure effective oversight of State programs. Public comments on these proposed State reporting requirements are requested. EPA particularly requests comments on whether the proposed reporting requirements are appropriate.

I. Variances and Exemptions

1. *Variances.* Under section 1415(a)(1)(A) of the SDWA, a State which has primary enforcement responsibility (i.e., primacy), or EPA as the primacy agent, may grant variances from MCLs to those public water systems that cannot comply with the MCLs because of characteristics of the water sources that are reasonably available. At the time a variance is

granted, the State must prescribe a compliance schedule and may require the system to implement additional control measures. The SDWA requires that variances may only be granted to those systems that have installed BAT (as identified by EPA). However, in limited situations a system may receive a variance if it demonstrates that the BAT would only achieve a *de minimis* reduction in contamination (see § 142.62(c)). Furthermore, before EPA or a State may grant a variance, it must find that the variance will not result in an unreasonable risk to health to the public served by the public water system. The levels representing an unreasonable risk to health for each of the contaminants in this proposal will be addressed in subsequent guidance (see discussion below). In general, the unreasonable risk to health (URTH) level would reflect acute and subchronic toxicity for shorter-term exposures and high carcinogenic risks for long-term exposures (as calculated using the linearized multistage model in accordance with the Agency's risk assessment guidelines; See URTH Guidance, 55 FR 40205, October 2, 1990).

Under section 1413(a)(4), States that choose to issue variances must do so under conditions, and in a manner, which are no less stringent than EPA allows in Section 1415. Of course, a State may adopt standards that are more stringent than the EPA standards. Before a State may issue a variance, it must find that the system is unable to (1) join another water system, or (2) develop another source of water and thus comply fully with all applicable drinking water regulations.

EPA specifies BATs for variance purposes. EPA may identify as BAT different treatments under section 1415 for variances than BAT under section 1412 for MCLs. EPA's section 1415 BAT findings may vary depending on a number of factors, including the number of persons served by the public water systems, physical conditions related to engineering feasibility, and the costs of compliance with MCLs.

Section 1415 Best Available Technology for Radionuclides. Table 22 shows the BATs that EPA is proposing for variance purposes under section 1415 for radionuclides. EPA has not proposed coagulation/filtration or lime softening as BAT for small systems (i.e., those systems ≤ 500 connections) for the purpose of granting variances because they are not technologically feasible for small systems, as discussed below.

TABLE 22.—PROPOSED BATs FOR VARIANCES UNDER SECTION 1415

Contaminant	BAT
Radon 222.....	1.
Radium 226.....	2, 3, 4.
Radium 228.....	2, 3, 4.
Uranium (N).....	2, 3, 4, 5.
Alpha particle emitters.....	3.
Beta particle and Photon emitters.....	3, 6.

Key to BATs:

- 1=Aeration: Packed Tower, spray, slat tray and other forms.
 2=Ion exchange.
 3=Reverse osmosis.
 4=Lime softening; except for systems serving ≤500 connections.
 5=Coagulation/filtration; except for systems serving ≤500 connections.
 6=Mixed bed ion exchange.

Coagulation/filtration and lime softening for radionuclides (i.e., uranium, radium-226 and radium-228) involve a greater degree of complexity than is required for removing conventional contaminants (i.e., turbidity removal). These differences result in increased operating time and level of expertise needed to operate coagulation/filtration and lime softening systems. Specific differences include: (a) Generally higher pH requirements for lime softening removal of radium and specific pH control for coagulation of uranium; (b) higher doses of chemical coagulants or lime for precipitation of radionuclides than for conventional turbidity removal or lime softening, which can complicate treatment operations with respect to chemical supply, and waste by-product (sludge) management; and (c) larger sedimentation basins and possible two-stage processes (one for turbidity softening and one for radionuclides precipitation). Consequently, coagulation/filtration and lime softening treatment are considered too complex in terms of operating time and levels of technical and managerial expertise usually available at small systems.

Costs of installing and operating some of the BATs listed in Table 22 (reverse osmosis and ion exchange) are high for small systems relative to costs for large systems, as shown by EPA estimates in tables 7 through 9. EPA is requesting comment on these technologies as BAT for variance purposes for small systems. EPA is continuing to evaluate what costs are reasonable for public water systems and in this regard, commenters are encouraged to provide a basis for their statements on what should constitute BAT for small systems.

With regard to BAT established under section 1415, EPA is requesting comment on: (1) Whether other technologies should be considered BAT under section 1415 for radionuclides; (2) whether it is

appropriate to exclude coagulation/filtration and lime softening for small systems; and (3) the appropriateness of reverse osmosis (RO) and ion exchange as BAT under section 1415 for small systems. EPA notes that RO offers the benefit of multiple contaminant removal and desalting, which makes RO technology especially attractive for some drinking water systems, including small systems. EPA also notes that ion exchange offers the benefit of water softening (i.e., removal of hardness) where hard water conditions prevail.

Use of POU devices and bottled water. Under section 1415(a)(1)(A)(ii), the State is to prescribe a schedule for implementation of any additional control measures it may require. The State may require the use of POU devices, bottled water, or other mitigation measures as an "additional control measures" during the period of a variance, as a condition to receiving the variance, if an unreasonable risk to health exists. The use of POU devices and bottled water would not be allowed for radon; only point of entry devices would be allowed for radon.

POU devices fail to treat water for the most significant risk from radon in water, the inhalation risk. EPA also recognizes that the use of POU devices to reduce levels of radon in water could present problems of disposal of the devices when their useful life is over. To prevent potential disposal problems, and to ensure that treatment required under variance provisions reduces risks, EPA is proposing to disallow the use of POU devices for radon for granting variances. Public comment on this proposed disallowance of POU devices to remove radon is requested.

2. Exemptions. Under Section 1416(a), EPA or a State may exempt public water systems from any requirements respecting an MCL or treatment technique requirements of an NPDWR, if it finds that (1) due to compelling factors (which may include economic factors), the PWS is unable to comply with the requirement; (2) the exemption will not result in an unreasonable risk to human health; and (3) the PWS was in operation on the effective date of the NPDWR, or for a system which was not in operation by that date, only if no reasonable alternative source of drinking water is available to the new system.

If EPA or a State grants an exemption to a public water system, it must at the same time prescribe a schedule for compliance (including increments of progress) and implementation of appropriate control measures that the State requires the system to meet while

the exemption is in effect. Under section 1416(2)(A), the schedule must require compliance within one year after the date of issuance of the exemption. However, section 1416(b)(2)(B) states that EPA or the State may extend the final date for compliance provided in any schedule for a period not to exceed a total of three years, if the public water system is taking all practicable steps to meet the standard and one of the following conditions applies: (1) The system cannot meet the standard without capital improvements which cannot be completed within the period of the exemption; (2) in the case of a system which needs financial assistance for the necessary implementation, the system has entered into an agreement to obtain financial assistance; or (3) the system has entered into an enforceable agreement to become part of a regional public water system. For public water systems which do not serve more than 500 service connections and which need financial assistance for the necessary improvements, EPA or the State may renew an exemption for one or more additional two-year periods if the system establishes that it is taking all practicable steps to meet the requirements noted above. Section 1416(b)(2)(C).

Under section 1416(d), EPA is required to review State-issued exemptions at least every three years and, if the Administrator finds that a State has, in a substantial number of instances, abused its discretion in granting exemptions or failed to prescribe schedules in accordance with the statute after following various procedures, the Administrator may revoke or modify those exemptions and schedules. EPA will use these procedures to strictly scrutinize exemptions from the MCLs granted by States and, if appropriate, will revoke or modify exemptions granted.

As a condition for receiving an exemption, the State may require the use of POU devices or bottled water for the duration of the exemption. The conditions are the same as those referenced in the variance section.

3. Unreasonable risks to health (URTH). As a part of the variance and exemption granting process, States must determine whether granting such a variance or exemption will pose an unreasonable risk to the health of the population served. While the granting of variances and exemptions, and the inherent URTH assessment, are State determinations, they occur within the overall context of State primacy and EPA oversight of the State's administration. EPA has therefore

developed guidance to assist States in making URTH determinations (EPA, 1990k), and published a draft of the guidance for public comment. For carcinogens, the draft guidance recommends that URTH be set at the top of EPA's risk range that is generally considered acceptable, 10^{-4} lifetime risk. Because EPA is proposing to regulate these contaminants at the most cost-effective level, bounded by 10^{-4} risk, the URTH values could be equal to the proposed MCLs, except for adjusted gross alpha and uranium. Adjusted gross alpha is a screening MCL; an URTH should not be considered to exist unless the individual contaminants in the adjusted gross alpha sample exceed a 10^{-4} risk. Uranium is being regulated based on its kidney toxicity; URTH guidance would need to be developed for uranium based on this toxic end point.

EPA solicits public comment on this approach to establishing URTH guidance for radionuclides.

VI. Public Notice Requirements

Under section 1414(c)(1) of the Act, each owner or operator of a public water system must give notice to persons served by it of (1) any violation of any MCL, treatment technique requirement, or testing provision prescribed by an NPDWR; (2) failure to comply with any monitoring requirement

under section 1445(a) of the Act; (3) existence of a variance or exemption; and (4) failure to comply with the requirements of a schedule prescribed pursuant to a variance or exemption.

The 1986 amendments required that EPA amend its current public notification regulations to provide for different types and frequencies of notice based on the differences between violations which are intermittent or infrequent and violations which are continuous or frequent, taking into account the seriousness of any potential adverse health effects which may be involved. EPA promulgated regulations to revise the public notification requirements on October 28, 1987 (52 FR 41534). The revised regulations state that violations of an MCL, treatment technique or variance or exemption schedule ("Tier 1 violations") contain health effects language specified by EPA which concisely and in non-technical terms conveys to the public the adverse health effects that may occur as a result of the violation. States and water utilities remain free to add additional information to each notice, as deemed appropriate for specific situations. This proposed rule contains specific health effects language for the contaminants which are in today's proposed rulemaking. EPA believes that the mandatory health effects language is the most appropriate way to inform the

affected public of the health implications of violating a particular EPA standard. The proposed mandatory health effects language in § 141.32(e) describes in non-technical terms the health effects associated with the proposed contaminants. Public comment is requested on the proposed language.

VII. Economic Impacts and Benefits

Executive Order 12291 requires EPA and other regulatory Agencies to perform a Regulatory Impact Analysis (RIA) for all "major" regulations. Major regulations are those which impose a cost of \$100 million or more on the national economy, or meet other criteria. EPA has determined that this proposed rule would be a major rule under the Executive Order, and has accordingly prepared an RIA which assesses the costs and benefits of the proposed regulations (EPA, 1991i). This regulation has also been reviewed by the Office of Management and Budget and their comments are available in the public docket.

Table 23 presents a summary of the results of the RIA. Approximately 28,000 public water systems would be required to install treatment or take other actions to comply with the proposed MCLs for these radionuclides. Total national costs would be approximately \$310 million per year.

TABLE 23.—NATIONAL COSTS AND BENEFITS OF PROPOSED RADIONUCLIDES MCLs

	Rn-222	Ra-226	Ra-228	Uranium	AGA (a)	Beta emitters	Total
Proposed MCL (b).....	300	20	20	20(c)	15	4(d)	
Systems affected.....	26,000	70	40	1,500	130	0	28,000
Treatment cost.....							
Total capital (\$M).....	1,600	190	40	350	230	0	2,400
Annual O&M (\$M).....	70	20	3	30	20	0	150
Total annual cost (\$M).....	180	30	6	60	40	0	310
Cancer cases avoided/yr.....	80	3	0.2	0.2	(e)	0	84
Monitoring (\$M/Yr) (f).....	5	0.003	0.89	0.003	0.64	0.25	7
State Implementation.....							
Initial (\$M).....	NA	NA	NA	NA	NA	NA	15-28
Annual (\$M).....	NA	NA	NA	NA	NA	NA	10-19
Annual household cost by system size:							
Very Small (25-500).....	120	630	650	580	770	0	
Small (501-3,300).....	30	150	150	180	340	0	
Medium (3,301-10,000).....	7	90	90	80	200	0	
Large (over 10,000).....	5	60	60	40	140	0	

(a) Adjusted gross alpha.

(b) MCLs are expressed in pCi/L unless otherwise noted.

(c) MCL for uranium is expressed in ug/L.

(d) MCL for beta emitters is expressed in mrems ede/year.

(e) Number of cases avoided per year is in the range of 0.2 to 1.4. The low end of the range is based on the risk factor associated with thorium-232; the high end is based on polonium-210 risk. Actual occurrence is likely to be characterized by a mix of several isotopes.

(f) Gross alpha is used as a screen for radium-226 and uranium.

Note: Total may not add due to rounding.

A large proportion of the water systems affected by this regulation would be small systems serving fewer than 500 people. Costs to households vary considerably over the range of

system sizes that would be covered by the proposed regulations, with smaller systems having higher costs, because these systems do not benefit from the engineering economies of scale that

large systems have. In the smallest of these systems (25 to 100 people), annual residential water bills could increase by \$700 to \$800 for treatment of radium or uranium. EPA recognizes that these

costs could prove very difficult to afford for small systems. Exemptions may be available through States to provide small systems with additional time to develop financing for water treatment as described in section V.I.2.

A. Regulatory Flexibility Analysis

The Regulatory Flexibility Act requires EPA to consider the effect of regulations on small entities, 5 U.S.C. 602 *et seq.* If there is a significant effect on a substantial number of small entities, the Agency must prepare a Regulatory Flexibility Analysis which describes significant alternatives that would minimize the impact on small entities. An analysis of the impact of the proposed radionuclides rule on small water systems is included in the RIA supporting this rule. The Administrator has determined that the proposed rule, if promulgated, will have a significant effect on a substantial number of small entities.

B. Paperwork Reduction Act

The information collection requirements in this proposed rule have been submitted for approval to the Office of Management and Budget (OMB) under the Paperwork Reduction Act, 44 U.S.C. 3501 *et seq.* An Information Collection Request document has been prepared by EPA (ICR No. 0270) and a copy may be obtained from Sandy Farmer, Information Policy Branch, (PM-223Y), U.S. Environmental Protection Agency, 401 M Street, SW., Washington, DC 20460, or by calling (202) 382-2740.

The total public reporting burden for this collection of information is estimated to be 674,517 hours, with an average of 4.7 hours per response, including time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information.

Send comments regarding the burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Chief, Information Policy Branch, (PM-223Y), U.S. Environmental Protection Agency, 401 M Street, SW., Washington, DC 20460; and to the Office of Information and Regulatory Affairs, Office of Management and Budget, Washington, DC 20503, marked "Attention: Desk Officer for EPA". The final rule will respond to any OMB or public comments on the information collection requirements contained in this proposal.

VIII. References

- 132 Cong. Rec. S6287, 6294 (May 21, 1986).
- Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Radium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, U.S. Public Health Service. (December 1990). [ATSDR, 1990]
- American Public Health Association; American Water Works Association; Water Pollution Control Federation. Standard Methods for the Examination of Water and Wastewater, 17th ed., (1989). [APHA, 1989]
- American Society for Testing and Materials, 1989 Annual Book of ASTM Standards, Water and Atmospheric Analysis, vol. 11.02, Philadelphia, PA (1989) [ASTM, 1989]
- Bean, J.A. et al. Drinking water and cancer incidence in Iowa. II. Radioactivity in drinking water. Am. J. Epidemiol. 111:6924-932 (1982). [Bean et al., 1982]
- Brandom, W.F. et al. Chromosome aberrations as a biological dose-response indicator of radiation exposure in uranium miners. Radiat. Res. 76:159-171 (1978). [Brandom, 1978]
- Brock v. Pierce County*, 476 U.S. 253 (1986)
- Correia, J.A. et al. The kinetics of ingested Rn-222 in humans determined from measurements with Xe-133. MA General Hospital, Boston, MA, unpublished report. (August 1987). [Correia, et al., 1987]
- Correia, J.A. et al. The kinetics of ingested Radon 222 in humans determined from measurements with Xe-133. Project Summary. PB 88-145297/AS (1988). [Correia et al., 1988]
- Crawford-Brown, D.J. A Calculation of Organ Burdens, Doses and Health Risks from Rn-222 Ingested in Water (Draft) (Feb. 11, 1990). [Crawford-Brown 1990].
- Crawford-Brown, D.J. Cancer Fatalities from Waterborne Radon (Rn-222). Risk Analysis, Vol. 11, No. 1, 135-143, (1991). [Crawford-Brown, 1991]
- Domingo, J.L. et al. The Developmental toxicity of uranium in mice. Toxicology 55:143-152. (1989). [Domingo et al., 1989a]
- Domingo, J.L. et al. Evaluation of the perinatal and postnatal effects of uranium in mice upon oral administration. Arch. Environ. Health (1989) 44:395. [Domingo et al., 1989b]
- Dunning, D.E. et al. A Combined Methodology for Estimating Dose Rates and Health Effects from Exposure to Radioactive Pollutants (draft). Prepared under Interagency Agreement EPA-78-D-X0231 by Oak Ridge National Laboratory (December 1980). [Dunning et al., 1980]
- Dunning, D.E. et al. An Assessment of Health Risk From Radiation Exposures. Health Physics 46:1035-1051. [Dunning et al., 1984]
- Dupree, E.A. et al. Mortality among workers at a uranium processing facility, the Linde Air Products Company Ceramics Plant, 1943-1949. Scand. J. Work Environ. Health Vol. 13:100-107 (1987). [Dupree et al., 1987]
- Ershow, A.G. and Cantor, K.P. Total water and tapwater intake in the United States: Population-based estimates of quantities and sources. Report prepared under National Cancer Institute Order #263-MD-810264. (1989). [Ershow and Cantor, 1989]
- Evans, R.D. et al. Radium metabolism in rats and the production of osteogenic sarcoma by experimental radium poisoning. Am. J. Roentgenol. Radium Therapy. 52:353-373 (1944). [Evans et al., 1944]
- Federal Register**. Vol. 40 No. 159. National Interim Primary Drinking Water Regulations; Final Rule. (Aug. 14, 1975) pp. 34324-34328 [40 FR 34324, Aug. 14, 1975]
- Federal Register**. Vol. 41 No. 133. National Interim Primary Drinking Water Regulations; Final Rule. (July 9, 1976), pp. 28402-28409. [41 FR 28402, July 9, 1976]
- Federal Register**. Vol. 50, No. 219. National Primary Drinking Water Regulations; Volatile Organic Chemicals; Proposed Rule (Nov. 13, 1985), 46902-46932. [50 FR 46902, Nov. 13, 1985]
- Federal Register**. Vol. 50, No. 219. National Primary Drinking Water Regulations; Synthetic Organic Chemicals, Inorganic Chemicals and Microorganisms, Evaluation of Health Effects and Determination of RMCLs; Proposed Rule (Nov. 13, 1985), 46936-47025. [50 FR 46936, Nov. 13 1985]
- Federal Register**. Vol. 51, No. 185. Guidelines for Carcinogenic Risk Assessment; Final Rule (September 24, 1986), 33992-34003. [51 FR 33992, September 24, 1986]
- Federal Register**. Vol. 51, No. 185. Guidelines for Estimating Exposures; Notices (September 24, 1986), 34042-34055. [51 FR 34042, September 24, 1986]
- Federal Register**. Vol. 51, No. 189. Water Pollution Control; National Primary Drinking Water Regulations; Radionuclides; Advance Notice of Proposed Rulemaking. (Sept. 30, 1986), 34836-34862. [51 FR 34836 Sept. 30, 1986]
- Federal Register**. Vol. 52, No. 130. National Primary Drinking Water Regulations for Synthetic Organic Chemicals; Monitoring for Unregulated Chemicals. (July 8, 1987), pp. 25690-25717. [52 FR 25690, July 8, 1987]
- Federal Register**. Vol. 52, No. 208. Drinking Water Regulations; Public Notification. (Oct. 28, 1987), pp. 41534-41550. [52 FR 41534, October 28, 1987]
- Federal Register**. Vol. 52, No. 212. Drinking Water; National Primary Drinking Water Regulation; Total Coliforms; Proposed Rule. (Nov. 3, 1987), pp. 42224-42245. [52 FR 42224, Nov. 3, 1987]
- Federal Register**. Vol. 54, No. 43. National Emission Standards for Hazardous Air Pollutants; Regulation of Radionuclides; Proposed Rule. (March 7, 1989), pp. 9612-9668. [54 FR 9612, Mar. 7, 1989]
- Federal Register**. Vol. 54, No. 97. National Primary and Secondary Drinking Water Regulations; Proposed Rule. (May 22, 1989), pp. 22062-22160. [54 FR 22062, May 22, 1989]

- Federal Register.** Vol. 54, No. 177. National Emission Standards for Hazardous Air Pollutants; Benzene; Rule and Proposed Rule. (September 14, 1989), pp. 38044-38190. [54 FR 38044, Sept. 14, 1989]
- Federal Register.** Vol. 54, No. 240. National Emission Standards for Hazardous Air Pollutants; Radionuclides; Final Rule and Notice of Reconsideration. (December 15, 1989), 51854. [54 FR 51854, Dec. 15, 1989]
- Federal Register.** Vol. 54, No. 243. National Primary Drinking Water Regulations Implementation; Primary Enforcement Responsibility; Final Rule. (December 20, 1989), pp. 52128-52140. [54 FR 52128, Dec. 20, 1989]
- Federal Register.** Vol. 55, No. 191. Variances and Exemptions for Primary Drinking Water Regulations; Unreasonable Risk to Health Guidance. Notice of Availability. (Oct. 2, 1990). p. 40205 [55 FR 40205, Oct. 2, 1990]
- Federal Register.** Vol. 56, No. 20. National Primary Drinking Water Regulations—Synthetic Organic Chemicals and Inorganic Chemicals; Final Rule (January 30, 1991), pp. 3528-3597. [56 FR 3528, Jan. 30, 1991]
- Federal Register.** Vol. 56, No. 106. National Primary Drinking Water Regulations Implementation Primary Enforcement Responsibility; Final Rule (June 3, 1991). pp. 25046-25050. [56 FR 25046]
- Finkel, M.P. Relative biological effectiveness of radium and other alpha emitters in CF No. 1 female mice. *Proc. Soc. Exp. Biol. Med.* 83:494-498. (1953). [Finkel, 1953]
- Finkel, M.P. et al. Toxicity of radium-226 in mice. In: Erickson A, ed. *Radiation induced cancer*. Vienna, Austria: International Atomic Energy Agency, pp. 389-391. (1969). [Finkel et al., 1969]
- H.R. Rep., No. 93-1185, in *Legislative History of the SDWA*, 97 Cong. 2d Sess., p. 549-550, 1982
- Haven, F.L. and Hodge, H.C. Toxicity following the parenteral administration of certain soluble uranium compounds. In: Voegtlin, C. and Hodge, H.C. eds. *Pharmacology and Toxicology of Uranium Compounds*. National Nuclear Energy Series, Div. VI, Vol. 1. New York: McGraw-Hill, pp. 281-308, (1949). [Haven and Hodge, 1949]
- Hess, C.T. et al. The Occurrence of Radioactivity in Public Water Supplies in the United States. *Health Physics*. Vol. 48 No. 5. (May 1985). [Hess et al., 1985].
- Hess, C.T. et al. Radon Transferred from Drinking Water into House Air. Prepared for Health Effects Research Division, Cincinnati, OH (January 1991). [Hess et al., 1991]
- Hess, C.T. and Brown, W.L. The Measurement of the Biotransfer and Time Constant of Radon from Ingested Water by Human Breath Analysis. Prepared under EPA Assistance Agreement CR-815158-01-0 for Health Effects Research Division, Cincinnati, OH (January 1991). [Hess and Brown, 1991]
- Hodge, H.C. A History of Uranium Poisoning (1824-1942). In: Hodge, H.C., Stannard, J.N., Hursh, J.B., eds. *Uranium, Plutonium, Transplutonic Elements: Handbook of Experimental Pharmacology XXXVI* (1973), pp. 6-67. New York: Springer-Verlag. [Hodge, 1973]
- Howland J.W. Studies on human exposures to uranium compounds. In: Voegtlin C., Hodge H.C. eds. *Pharmacology and Toxicology of Uranium Compounds*. National Nuclear Energy Series, Div. VI, Vol. 1. New York: McGraw Hill. (1949). [Howland, 1949]
- Humphreys et al., The induction by Ra-224 of myeloid leukemia and osteosarcoma in male CBA mice. *Int. J. Radiat. Biol.* 47:239-247 (1985). [Humphreys et al., 1985].
- International Commission on Radiological Protection (ICRP). Report of the Task Group on Reference Man. ICRP Publication 23. Oxford: Pergamon Press (1975). [ICRP, 1975]
- International Commission on Radiological Protection (ICRP). Recommendations of the International Commission on Radiological Protection. ICRP Publication 26. Oxford: Pergamon Press (1977). [ICRP, 1977]
- International Commission on Radiological Protection (ICRP). Limits for Intake of Radionuclides by Workers. ICRP Publication 30, Part 1. *Annals of the ICRP* Vol. 2. (3/4) Oxford: Pergamon Press (1979). [ICRP, 1979]
- International Commission on Radiological Protection (ICRP). Limits for Intakes of Radionuclides by Workers ICRP Publication 30, Part 2. *Annals of the ICRP* Vol. 4 (3/4) Oxford: Pergamon Press (1980). [ICRP, 1980]
- International Commission on Radiological Protection (ICRP). Limits for Intakes of radionuclides by workers. ICRP Publication 30, Part 3. *Annals of the ICRP* Vol. 6 (2/3) Oxford: Pergamon Press (1981). [ICRP, 1981]
- International Commission on Radiological Protection (ICRP) Lung Cancer Risk From Indoor Exposure to Radon Daughters. ICRP Publication 50. Oxford: Pergamon Press. (1987). [ICRP, 1987]
- Keane, A.T. et al. Non-stochastic effects of Ra-226 and Ra-228 in the human skeleton. In: *Biological effects of low-level radiation*. Vienna, Austria: International Atomic Energy Agency. 329-350. (1983). [Keane et al., 1983]
- Kinner et al., Radon Removal Techniques for Small Community Public Water Supplies. Prepared under cooperative agreement no. CR 812602-01-0 for Risk Reduction Engineering Laboratory, Office of Research and Development. Cincinnati, OH (June 1989). [Kinner et al., 1989]
- Kinner et al. Radon Removal Using Point-Of-Entry Water Treatment Techniques. Prepared under cooperative agreement no. CR 812602-01-0 for Risk Reduction Engineering Laboratory, Office of Research and Development. Cincinnati, OH (June 1990). [Kinner et al., 1990]
- Kinner, N.E. Memorandum to Greg Helms, ODW from Nancy Kinner. Variability in Radon Occurrence Data (July 3, 1990). [Kinner, 1990]
- Leggett, R.W. The Behavior and Chemical Toxicity of U in the Kidney: A Reassessment. *Health Physics*, Vol. 57, No. 3, 365-383. September, 1989. [Leggett, 1989]
- Lowry, 1991. Measuring Low Radon Levels in Drinking Water Supplies. *JAWWA* April 1991, pp. 149-153 [Lowry, 1991]
- Lyman, G.H. et al. Association of leukemia with radium groundwater contamination. *JAMA* 254:621-626 (1985). [Lyman et al., 1985]
- Lyman, G.H., and Lyman, C.G. Leukemia and groundwater contamination [letter]. *JAMA* 256:2676-2677 (1986). [Lyman and Lyman, 1986]
- Maletskos, C.J. et al. The metabolism of intravenously administered radium and thorium in human beings and the relative absorption from the human gastrointestinal tract of radium and thorium in simulated radium dial paints. In: *Radium and mesothorium poisoning and dosimetry and instrumentation techniques in applied radioactivity*. Cambridge, MA: MIT Physics Department. 202-317. (1966). [Maletskos et al., 1966]
- Maletskos, C.J. et al. Retention and absorption of Ra-224 and Th-234 and some dosimetric consideration of Ra-224 in human beings. In: Mays, C.E. et al. eds. *Delayed effects of bone-seeking radionuclides*. Salt Lake City, UT: University of Utah Press. 29-49. (1969). [Maletskos et al., 1969]
- Maynard, E.A. and Hodge, H.C. Study of toxicity of various uranium compounds when fed to experiment animals. In: Voegtlin C., Hodge H.C. eds. *Pharmacology and Toxicology of Uranium Compounds*. National Nuclear Energy Series, Div. VI, Vol. 1. pp. 309-376. New York: McGraw Hill. (1949). [Maynard and Hodge, 1949]
- Maynard, E.A. et al. Oral toxicity of uranium compounds. In: Voegtlin C., Hodge H.C. eds. *Pharmacology and Toxicology of Uranium Compounds*. National Nuclear Energy Series, Div. VI, Vol. 1. New York: McGraw Hill. (1953), pp. 1221-1369. [Maynard et al., 1953]
- Mays, C.W. and Speiss, H. Bone sarcomas in patients given radium-224. In: Boice, J.D., Fraumeni, J.F. eds. *Radiation carcinogenesis; epidemiology and biological significance*. New York: Raven Press. 241-252 (1984). [Hays and Spiess, 1984]
- Mays, C.W. et al. Cancer Risk from the Lifetime Intake of Ra and U Isotopes. *Health Physics* Vol. 48 No. 5 (May 1985). [Mays et al., 1985]
- Moeller, D.W. and Underhill, D.W. Final report on the study of the effects of building materials on population dose equivalent. School of Public Health, Harvard University. (1976). [Moeller and Underhill, 1976]

- Motor Vehicles Manufacturers Assn. v. State Farm Mutual Automobile Insurance Co.*, 463 U.S. 29, 42 (1983).
- Muller J. et al. Early induction of leukemia (malignant lymphoma) in mice by protracted low alpha-doses. *Health Physics* (1988) 54:461-463. [Muller et al., 1988]
- National Academy of Sciences. National Research Council. The Effects on Populations of Exposure to Low Levels of Ionizing Radiation (BEIR III) (1980). [NAS, 1980]
- National Academy of Sciences. National Research Council. Health Risks of Radon and Other Internally Deposited Alpha-Emitters (BEIR IV) (1988). [NAS, 1988]
- National Academy of Sciences. National Research Council. Health Effects of Exposure to Low Levels of Ionizing Radiation (BEIR V) (1990). [NAS, 1990]
- National Academy of Sciences. National Research Council. Comparative Dosimetry of Radon in Mines and Homes. (1991). [NAS, 1991]
- National Council on Radiation Protection and Measurements (NCRP). Radiological assessment: Predicting the transport, bioaccumulation and uptake by man of radionuclides released to the environment. NCRP Report No. 76. Bethesda, MD. (1984). [NCRP, 1984a]
- National Council on Radiation Protection and Measurements (NCRP). Exposures from the Uranium Series With Emphasis on Radon and Its Daughters. NCRP Report, No. 77. Bethesda, MD (1984). [NCRP, 1984b]
- National Institute for Occupational Safety and Health (NIOSH). Radon progeny in underground mines. Publication No. 88-101. (1987). [NIOSH, 1987]
- National Radiological Protection Board (NRPB). Health Effects Models Developed from the 1988 UNSCEAR Report. Chilton, Didcot, Oxfordshire, UK. (1988) [NRPB, 1988]
- Nero, A.V.; Schwehr, M.B.; Nazaroff, K.L. et al. Distribution of Airborne Radon 222 Concentration in U.S. Homes. Vol. 234 *Science* (1986). [Nero et al., 1986]
- New Jersey State Department of Environmental Protection—Division of Environmental Quality—Bureau of Radiation and Inorganic Analytical Services. Determination of Radium 228 in Drinking Water (August, 1990). [NJ DEQ, 1990]
- New York State Department of Health. Determination of Radium 226 and Radium 228 (Ra-02), Radiological Sciences Institute Center for Research. (June, 1982). [NY State DOH, 1982]
- Norris, W.P. et al. Studies of the metabolism of radium in man. *Am. J. Roentg. Rad. Therapy Nuclear Med.* 73:785-802 (1955). [Norris et al., 1955]
- Northern Plains Resources Council v. EPA*, 645 F. 2d 1349 (9 Circ. 1981).
- Oakley, D.T. Natural radiation exposure in the United States. ORP/SID 72-1 (1972). [Oakley, 1972]
- Paternian, J.L. et al. The Effects of Uranium on Reproduction, Gestation, and Postnatal Survival in Mice. *Ecotoxicol. Environ. Safety* 17: 291-296. (1989). [Paternian et al., 1989]
- Petersen, N.J. et al. An epidemiologic approach to low-level radium-226 exposure. *Public Health Rep.* 81:805-814 (1966). [Petersen et al., 1966]
- Raabe, O.G., et al. Dose-response relationships for bone tumors in beagles exposed to Ra-226 and Sr-90. *Health Phys.* (1981), 40:863-880. [Raabe et al., 1981]
- Radiation Effects Research Foundation (RERF). Life Span Study Report 11, Part 1. Comparison of Risk Coefficients for Site-Specific Cancer Mortality Based on the DS86 and T65DR Shielded Kerma and Organ Doses. (November, 1987). RERF TR 12-87 [RERF, 1987]
- Radioactivity in Drinking Water. Proceedings of the National Workshop on Radioactivity in Drinking Water, held May 24-26, 1983 at the Tidewater Inn, Easton, MD, published as a special issue of *Health Physics*, Vol. 48, No. 5, (May, 1985) 535-693. [Health Physics, 1985]
- Rowland et al. Dose-response relationships for female radium dial workers. *Radiation Research*. Vol. 76 (1978), 368-383. [Rowland et al., 1978]
- Rundo, J. et al. Current (1984) status of the study of Ra-226 and Ra-228 in humans at the Center for Human Radiobiology. In: Gossner W., Gerber G.B., Hagen U., Luz A., eds. *The Radiobiology of Radium and Thorotrast*. Baltimore: Urban and Schwarzenberg, Baltimore (1986). pp. 14-21. [Rundo et al., 1986]
- Schlenker, R.A. Risk estimates for bone. In: Critical issues in setting radiation dose limits. Proceedings No.3, Bethesda, MD: National Council on Radiation Protection and Measurements. (1982), pp. 153-163. [Schlenker, 1982]
- Schliekelman, R.J. Determination of Radium Removal Efficiencies in Iowa Water Supply Treatment Processes. EPA-ORP/TAD-76-1 (June 1976). [Schliekelman, 1976]
- Science Advisory Board, Radiation Advisory Committee. Review of ODW's Criteria Documents and Related Reports for Uranium, Radium, Radon, and Manmade Beta-Gamma Emitters (Draft). October 13, 1990. [SAB/RAC, 1990]
- Sevc, J. et al. Cancer in man after exposure to Rn daughters. *Health Physics* 54:27-46 (1988). [Sevc et al., 1988]
- Sharpe, W.D. Chronic radium intoxication: Clinical and autopsy findings in long-term New Jersey survivors. *Environ. Res.* 8:243-383 (1974). [Sharpe, 1974]
- Sorg, T.J. et al. Removal of Radium-226 from Sarasota County, Florida Drinking Water by Reverse Osmosis. JAWWA (April 1980), 230-237. [Sorg et al., 1980]
- Sorg, T.J. Methods for Removing Uranium from Drinking Water. JAWWA (July 1988), Vol. 80, No.7, pp. 105-111. [Sorg, 1988]
- Stebbing, J.H., et al. Mortality from cancers of major sites in female radium dial workers. *Am. J. Ind. Med.* Vol. 5 (1984) 435-459. [Stebbing et al., 1984]
- Sullivan, R.E. et al. Estimates of Health Risk from Exposure to Radioactive Pollutants (draft). Prepared under Interagency Agreement 40-1073-80 by Oak Ridge National Laboratory (November, 1981). ORNL/TM-7745 [Sullivan et al., 1981]
- Taylor, G.N. et al. Radium induced eye melanomas in dogs. *Radiat. Res.* 51:361-373. (1972). [Taylor et al., 1972]
- U.S. Department of Energy (DOE). Radon Inhalation studies in animals. U.S. Department of Energy. Washington, DC DOE/ER-0396 (1988). [DOE, 1988]
- U.S. Department of Energy (DOE), Environmental Measurements Laboratory. EML Procedures Manual, 27th edition, (November 1990). [DOE, 1990]
- U.S. Environmental Protection Agency. Interim Radiological Methodology for Drinking Water. EPA-600/4-75-008, (March, 1976). [EPA, 1976]
- U.S. Environmental Protection Agency. Memorandum, Hawkins to Regional Administrators, I-X, RE: Guidance for Determining BACT under SPD. January 4, 1979. [EPA, 1979a]
- U.S. Environmental Protection Agency. Radiochemical Analytical Procedures for Analysis of Environmental Samples. EMSL-LV-0539-17. (March, 1979). [EPA, 1979b]
- U.S. Environmental Protection Agency. Prescribed Procedures for Measurement of Radioactivity in Drinking Water. Environmental Monitoring and Support Laboratory, Cincinnati, OH. EPA-600/4-80-032, August, 1980. [EPA, 1980]
- U.S. Environmental Protection Agency and U.S. Department of Energy, Oak Ridge National Laboratory. Uranium in U.S. Surface, Ground, and Domestic Waters, Vol. 1 (1981) EPA-570/9-81-001 and ORNL/EIS-192, p.8. [EPA/ORNL, 1981]
- U.S. Environmental Protection Agency. Determination of Lead-210 in Drinking Water: Method 909. Velten, R.J., and Jacobs, B.J., Environmental Monitoring and Support Laboratory. (March 1982) [EPA, 1982]
- U.S. Environmental Protection Agency, Office of Radiation Programs. Eastern Environmental Radiation Facility Radiochemistry Procedures Manual. Eastern Environmental Radiation Facility, Montgomery, AL. EPA 520/5-84-006, August, 1984. [EPA, 1984a]
- U.S. Environmental Protection Agency. Technologies and Costs for the Removal of Radium from Potable Water Supplies. Prepared by V.J. Ciccone and Associates. (July 31, 1984). [EPA, 1984b]
- U.S. Environmental Protection Agency. Nationwide Occurrence of Radon and Other Natural Radioactivity in Public Water Supplies (The Nationwide Radon Survey). Eastern Environmental Radiation Facility, Montgomery, AL, EPA 520/5-85-008, (October 1985). [EPA, 1985a]

- U.S. Environmental Protection Agency. Technologies and Costs for the Removal of Uranium from Potable Water Supplies (Revised Final Draft). Prepared by V.J. Ciccone and Associates (Oct., 30, 1985). [EPA, 1985b]
- U.S. Environmental Protection Agency. Test Procedure for Gross Alpha Particle Activity in Drinking Water. J.O. 70.12. (December, 1985). [EPA, 1985c]
- U.S. Environmental Protection Agency. Project Summary: Barium and Radium in Water Treatment Plant Wastes. Prepared by V.J. Snoeyink et al. for EPA Water Engineering Research Laboratory, Cincinnati OH (March 1985). [EPA, 1985d]
- U.S. Environmental Protection Agency. Statistical Analyses of Analytical Methods for Radionuclides in Drinking Water (Final Report). Prepared by Research Planning Institute, Columbia, SC (May, 1986) for ODW under Assignment No. 041422. [EPA, 1986a]
- U.S. Environmental Protection Agency. Technologies and Costs for the Removal of Man-Made Radionuclides from Potable Water Supplies (Revised Final Draft). Prepared by V.J. Ciccone & Assoc. (March 10, 1986). [EPA, 1986b]
- U.S. Environmental Protection Agency. Supplement to Technologies and Costs for the Removal of Uranium from Potable Water Supplies (Draft). Prepared by Malcolm Pirnie, Inc. (December 30, 1986). [EPA, 1986c]
- U.S. Environmental Protection Agency. Technologies and Costs for the Treatment and Disposal of Waste Byproducts from Water Treatments for the Removal of Inorganic and Radioactive Contaminants (Draft). (September 1986). [EPA, 1986d]
- U.S. Environmental Protection Agency. Air Quality Criteria Document for Lead, Vol. II, Environmental Criteria and Assessment Office. Research Triangle Park, NC, EPA-600/8-83/028bF (1986). [EPA, 1986e]
- U.S. Environmental Protection Agency. A Citizen's Guide to Radon: What It Is and What To Do About It (August 1986). [EPA 1986f]
- U.S. Environmental Protection Agency. Analysis of Occurrence, Control and/or Removal of Radionuclides in Small Drinking Water Systems in Virginia. Prepared by V.J. Ciccone and Associates under EPA contract No. 68-01-7088 (September 1987). [EPA, 1987a]
- U.S. Environmental Protection Agency. Technologies and Costs for the Removal of Radon from Potable Water Supplies (Fourth Draft). Prepared by Malcolm Pirnie, Inc. (January 6, 1987). [EPA, 1987b]
- U.S. Environmental Protection Agency. Supplement to Technologies and Costs for the Removal of Man-Made Radionuclides from Potable Water Supplies (First Draft). Prepared by Malcolm Pirnie (January 8, 1987). [EPA, 1987c]
- U.S. Environmental Protection Agency. Supplement to Technologies and Costs for the Removal of Radium from Potable Water Supplies (First Draft). Prepared by Malcolm Pirnie (January 7, 1987). [EPA, 1987d]
- U.S. Environmental Protection Agency. Two Test Procedures for Radon in Drinking Water, Interlaboratory Collaborative Study. EPA/600/2-87/082, (March 1987). [EPA, 1987e]
- U.S. Environmental Protection Agency. Project Summary: Removal of Uranium from Drinking Water by Ion Exchange and Chemical Clarification. Prepared by Steven W. Hanson et al. for EPA Water Engineering Research Laboratory, Cincinnati OH (Dec. 1987). [EPA, 1987f]
- U.S. Environmental Protection Agency. Estimates of Co-Occurrence of Radionuclides in Drinking Water. Prepared by Science Applications International Corporation (August 17, 1988) under contract no. 68-03-3514. [EPA, 1988a]
- U.S. Environmental Protection Agency. Memorandum to Arthur Perler, STB from Jon Longtin, WSTB regarding Distribution Tables for the National Inorganics and Radionuclides Survey (NIRS) Results, (February 23, 1988). [EPA, 1988b]
- U.S. Environmental Protection Agency. Memorandum to Stephen Clark, ODW from Warren Peters, PAB and Chris Nelson, ORP regarding Preliminary Risk Assessment for Radon Emissions from Drinking Water Treatment Facilities, (June 28, 1988). [EPA, 1988c]
- U.S. Environmental Protection Agency. Memorandum to Susan MacMullin and Michael Morton, ODW, from Frank Letkiewicz and Barbara Minkser, Wade Miller Assoc., Inc. regarding Radionuclide Co-Occurrence Analyses (August 12, 1988). [EPA, 1988d]
- U.S. Environmental Protection Agency. Aeration Alternatives for Radon Reduction—Addendum to Technologies and Costs for the Removal of Radon from Potable Water Supplies. Prepared by Malcolm Pirnie, Inc. (April 25, 1988). [EPA, 1988e]
- U.S. Environmental Protection Agency. Letter to W. Schull, SAB/RAC from L. Thomas, EPA regarding radon risk estimates (November 23, 1988). [EPA, 1988f]
- U.S. Environmental Protection Agency. Project Summary: A Study of Possible Economical Ways of Removing Radium from Drinking Water. Prepared by R.L. Valentine et al. for EPA Water Engineering Research Laboratory, Cincinnati, OH (April, 1988). [EPA, 1988g]
- U.S. Environmental Protection Agency. Project Summary: Radium Removal for a Small Community Water Supply System. Prepared by Kenneth A. Mangelson for EPA Water Engineering Research Laboratory, Cincinnati OH (Sept. 1988). [EPA, 1988h]
- U.S. Environmental Protection Agency. Risk Assessments Methodology. Environmental Impact Statement. NESHAPS for Radionuclides. Background Information Document—Vol. 1. Office of Radiation Programs. EPA/520/1-89-005 (September 1989). [EPA, 1989a]
- U.S. Environmental Protection Agency. Memorandum to Greg Helms, ODW from Marc Parrotta, ODW regarding an Analysis of Potential Radon Emissions from Water Treatment Plants using the MINEDOSE Code, (November 22, 1989). [EPA, 1989b]
- U.S. Environmental Protection Agency. Occurrence of Man-Made Radionuclides in Public Drinking Water Supplies (Draft). Prepared by Wade Miller Associates, Inc. (November 20, 1989). [EPA, 1989c]
- U.S. Environmental Protection Agency. Letter to Greg Helms, ODW from Thomas Banks, Wade Miller Assoc. regarding The Lucas Cell Method of Testing for Radon in Water (November 14, 1989). [EPA, 1989d]
- U.S. Environmental Protection Agency. Memorandum to G. Helms, ODW from T. Banks, Wade Miller Assoc. regarding liquid scintillation counting, (1989). [EPA, 1989e]
- U.S. Environmental Protection Agency. Drinking Water Criteria Document for Uranium. External Review Draft. Prepared by Dynamac Corp. (November 1989). [EPA, 1989f]
- U.S. Environmental Protection Agency. Memorandum from Margo Oge, Director, Radon Division. "Current ORP Estimate of Annual Radon-Induced Lung Cancer Deaths in the General Population." (August 17, 1989). [EPA, 1989g]
- U.S. Environmental Protection Agency. Suggested Guidelines for the Disposal of Drinking Water Treatment Wastes Containing Naturally-Occurring Radionuclides. Office of Drinking Water. (July 1990). [EPA, 1990a]
- U.S. Environmental Protection Agency. Manual for the Certification of Laboratories Analyzing Drinking Water. Criteria and Procedures. Quality Assurance. Third Edition. Office of Water, EPA/570/9-90/08 (April 1990). [EPA, 1990b]
- U.S. Environmental Protection Agency. Memorandum to Joseph Cotruvo, ODW from Jerome Puskin, ORP regarding Human Radon-222 Lifetime Risk Estimates from Ingestion (March 28, 1990). [EPA, 1990c]
- U.S. Environmental Protection Agency. Memorandum to Folsom from McFarland regarding cost revisions for radium, radon, and uranium to account for new system level treatment design flows adopted by EPA. (May, 1990). [EPA, 1990d]
- U.S. Environmental Protection Agency. Memorandum to Greg Helms, ODW from Neal Nelson, ORP regarding draft Drinking Water Health Criteria Document for Uranium (July 5, 1990). [EPA, 1990e]
- U.S. Environmental Protection Agency. Occurrence and Exposure Assessment

- for Radon in Public Drinking Water Supplies (draft). Prepared by Wade Miller Associates, Inc. (September 25, 1990). [EPA, 1990f]
- U.S. Environmental Protection Agency. Occurrence and Exposure Assessment for Radium-226 in Public Drinking Water Supplies (draft). Prepared by Wade Miller Associates, Inc. (April 30, 1990). [EPA, 1990g]
- U. S. Environmental Protection Agency. Occurrence and Exposure Assessment for Uranium in Public Drinking Water Supplies (draft). Prepared by Wade Miller Associates, Inc. (April 26, 1990). [EPA, 1990h]
- U.S. Environmental Protection Agency. "Estimation of Risks from Indoor Radon Exposures" (February 15, 1990). [EPA, 1990i]
- U.S. Environmental Protection Agency. Memorandum T. Banks, WMA to G. Helms, February 21, 1990, on Laboratories Conducting Analysis of Radon in Drinking Water. [EPA, 1990j].
- U.S. Environmental Protection Agency. "Guidance for Developing Health Criteria for Determining Unreasonable Risks to Health (draft), (1990). [EPA, 1990k]
- U.S. Environmental Protection Agency. Quantitative Risk Assessment for Radon in Drinking Water. External Review Draft. Prepared by Dynamac Corp. (May 1990). [EPA, 1990l]
- U. S. Environmental Protection Agency. Technical Support Document for the 1990 Citizen's Guide to Radon (Draft; August 16, 1990). [EPA 1990m]
- U.S. Environmental Protection Agency. Occurrence and Exposure Assessment for Radium-228 in Public Drinking Water Supplies (draft). Prepared by Wade Miller Associates under contract No. 69-03-3514. (November 30, 1990). [EPA, 1990n]
- U.S. Environmental Protection Agency. Memorandum from Elliott, Assistant Administrator and General Counsel to Habicht, Deputy Administrator regarding regulation of radionuclides in drinking water, (July 30, 1990). [EPA, 1990o]
- U.S. Environmental Protection Agency. Drinking Water Criteria Document for Gross Alpha Emitters (Draft). Prepared by Clement International Corp. (June 1991). [EPA, 1991a]
- U.S. Environmental Protection Agency. Criteria Document for Radium in Drinking Water (Draft). Prepared by Life Systems, Inc. (June 1991). [EPA, 1991b]
- U.S. Environmental Protection Agency. Drinking Water Criteria Document for Radon in Drinking Water (Draft). Prepared by Life Systems, Inc. (June 1991). [EPA, 1991c]
- U.S. Environmental Protection Agency. Criteria Document for Man-Made Radionuclides in Drinking Water (Draft). Prepared by Clement International Corp. (June 1991). [EPA, 1991d]
- U.S. Environmental Protection Agency. Drinking Water Criteria Document for Uranium (Draft). Prepared by Clement International Corp. (June 1991). [EPA, 1991e].
- U.S. Environmental Protection Agency. Occurrence and Exposure Document for Gross Alpha Radiation (Draft). Prepared by Wade Miller Associates under contract No. 69-03-3514. (1991). [EPA, 1991f].
- U.S. Environmental Protection Agency. Occurrence and Exposure Assessment of Pb-210 in Drinking Water, Food, and Air (Draft)—Addendum to Occurrence of Man-Made Radionuclides in Public Drinking Water Supplies. Prepared by Wade Miller Associates, Inc. (May 20, 1991). [EPA, 1991g]
- U.S. Environmental Protection Agency. Radon in Drinking Water: Assessment of Exposure Pathways. Prepared by Life Systems, Inc. (June 1991) [EPA, 1991h].
- U.S. Environmental Protection Agency. Regulatory Impact Analysis of Proposed National Primary Drinking Water Regulations for Radionuclides (Draft). Prepared by Wade Miller Associates (June 14, 1991). [EPA, 1991i]
- U.S. Environmental Protection Agency. Response To Comments Received on the NPDWRs: Radionuclides in Drinking Water—Advance Notice of Proposed Rulemaking, September 30, 1986. (June 1991). [EPA, 1991j]
- U.S. Environmental Protection Agency. Technologies and Costs for the Removal of Alpha Emitters from Potable Water Supplies. Prepared by Malcolm Pirnie, Inc. (Feb., 1991). [EPA, 1991k]
- U.S. Environmental Protection Agency. "Proposed Revisions in EPA Estimates of Radon Risks and Associated Uncertainties" (April, 1991). [EPA, 1991l]
- U.S. Environmental Protection Agency. Memorandum to G. Helms from I. Deloatch regarding estimated cost of analyses for radionuclides, (March 27, 1991). [EPA, 1991m]
- U.S. Environmental Protection Agency. Radiation Research and Methods Validation. Annual Report, FY 1990. EPA 600/X-91/055, (May 1991). [EPA, 1991n].
- U.S. Environmental Protection Agency. Occurrence and Exposure Assessment for Uranium in Public Drinking Water Supplies. Revision 2. Prepared by Wade Miller Associates, Inc. (June 13, 1991) [EPA, 1991o]
- U.S. Environmental Protection Agency. Health Effects Assessment Summary Tables. Annual FY-1991. OERR 9200.6-303 (91-1) NTIS PB91-921199. [EPA, 1991p]
- U.S. Environmental Protection Agency. Method 913—Radon in Drinking Water by Liquid Scintillation. EMSL/LV, (June 1991) [EPA, 1991q]
- U.S. Environmental Protection Agency. Memorandum Deloatch to Helms, PQL Assessments for Radionuclides. (June 13, 1991) [EPA, 1991r]
- U.S. Environmental Protection Agency. IRIS Print-out for Uranium (soluble salts); Revised 10/1/89. (June 14, 1991) [EPA, 1991s]
- U.S. Geological Survey (USGS). Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, Book 5, Chapter A5, in Techniques of Water-Resources Investigations of the USGS. (1989) [USGS, 1989]
- United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR). Ionizing Radiation: Sources and Biological Effects. Report to the General Assembly. New York (1982). [UNSCEAR, 1982]
- United Nation's Scientific Committee on the Effect of Atomic Radiation (UNSCEAR). Sources, Effects and Risks of Ionizing Radiation. Report to the General Assembly. New York, (1988). [UNSCEAR, 1988]
- Vitz, E. Toward a Standard Method for Determining Waterborne Radon. Health Physics, vol 60, No. 6 pp. 817-829 (June 1991). [Vitz, 1991]
- Wilkinson, G. Gastric Cancer in New Mexico counties with significant deposits of uranium. Arch. Environ. Health. (1985), 40:307. [Wilkinson, 1985]
- Wrenn, M.E. et al. Metabolism of Ingested U and Ra. Health Physics. Vol. 48, No. 5 (1985). [Wrenn et al., 1985]

Appendix A—Fundamentals of Radioactivity in Drinking Water

To assist commenters, the following section provides a summary of concepts and definitions involving radioactivity. The definitions include those in the Interim Regulations along with several additions, one of which is being considered (i.e., curie) to be added to 40 CFR 141.2.

Definitions

(a) *Dose equivalent* means the product of the absorbed dose from ionizing radiation and such factors which account for differences in biological effectiveness due to the type of radiation and its distribution in the body as specified by the International Commission on Radiological Units and Measurements (ICRU).

(b) *Rem* means the unit of dose equivalent from ionizing radiation to the total body or any internal organ or organ system. It is equal to the absorbed dose in rads multiplied by a quality factor (to account for different radiation types). A rem ede (effective dose equivalent) is a dose to organs adjusted for different radiation types and by an organ weighting factor to account for organ sensitivity to the effect of radiation. A "millirem" (mrem) is 1/1,000 of a rem.

(c) *Curie* means a special unit of activity equal to a nuclear transformation rate of 3.7×10^{10} disintegrations/second. One picocurie is equal to 10^{-12} curies, which is approximately 2 disintegrations per minute.

(d) *Gross alpha particle emission activity* means the total alpha particle radioactivity measured in an aliquot of an evaporated water sample.

(e) *Man-made beta particle and photon emitters* means all radionuclides emitting

beta particles and/or photons that have been produced artificially and do not exist naturally.

(f) *Gross beta particle activity* means the total radioactivity due to beta particle emissions measured in a aliquot of a evaporated water sample.

(g) *Becquerel (Bq)* is a special unit of radioactivity in the international system of units (SI). One Becquerel is equal to one disintegration per second.

(h) *Sievert (Sv)* means the unit of dose equivalent in the international system of units (SI) from ionizing radiation to the total body or any internal organ or organ system. One Sievert equals 100 rem.

(i) *Effective dose equivalent* means the sum of the products of the dose equivalents in individual organs and the organ weighing factor.

(j) *Organ weighting factor* means the ratio of the stochastic risk for that organ to the total risk when the whole body is irradiated uniformly.

(k) *Natural uranium* means uranium with combined uranium-234 plus uranium-235 plus uranium-238 which has a varying isotopic composition but typically is 0.006% uranium-234, 0.7% uranium-235, and 99.27% uranium-238.

(l) *Activity* means the nuclear transformations of a radioactive substance which occur in a specific time interval.

Fundamentals of Nuclear Structure and Radioactivity

This section has been included to provide background information for those not familiar with nuclear chemistry. It is written in broad and general terms and some statements may be simplified.

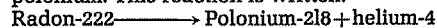
An atom consists of a heavy concentration of mass at the center (the nucleus) surrounded by shells of electrons in different orbits. The primary constituents of the nucleus are neutrons and protons. The neutrons have no net electric charge while the protons have a positive charge. The orbital electrons have a negative charge and in the un-ionized atoms are equal in number to the protons, making the atom neutral in overall charge.

The number of protons in the nucleus determines the chemical element and its atomic number. A given element can have more than one particular number of neutrons. Variation in the number of neutrons does not change the chemical properties (the element is the same) but it can produce considerable change in the stability of the element to radioactive decay. Atoms with the same number of protons but different number of neutrons are called "isotopes." For example, if an atom has 86 protons, it is radon. There are three principal isotopes of radon containing 133, 134 and 136 neutrons. The atomic mass number is the total number of protons and neutrons in the nucleus and this sum is usually used to label isotopes. The three isotopes of radon have atomic masses of $86 + 133 = 219$, $86 + 134 = 220$ and $86 + 136 = 222$. Symbolically these can be written as: Radon-219 Radon-220 Radon-222.

Since the atomic number and the chemical symbol are synonymous, the number of protons is usually omitted in the nomenclature.

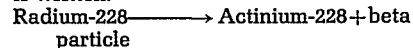
These radionuclides decay by emission of alpha and beta particles and gamma rays. An alpha particle, the heaviest nuclear radiation, consists of two protons and two neutrons. (A proton or neutron is about 2,000 times as massive as an electron.) A negative beta particle is an electron emitted from the nucleus as a result of neutron decay. An electron can be "created" and ejected from a nucleus by a neutron decaying into a proton (which remains in the nucleus) and an electron (which is ejected as a beta particle) and also a neutrino. As a result of this process the nucleus has one more proton and thus has become the atom of a different element with atomic number one greater than the parent atom. (There can also be a nuclear transformation in which a proton emits a positive beta particle, or positron, and is transformed into a neutron which remains in the nucleus). A gamma ray is a form of electromagnetic radiation. Other forms of electromagnetic radiation are light, radio waves, infrared radiation, ultraviolet radiation and x-rays.

The process of alpha and beta radioactive decay leads to a different element while gamma ray emission does not. The isotope that decays is called the parent. The resulting isotope (if a different element) is called the progeny. For example, radon-222 decays by emitting an alpha particle to the progeny polonium. This reaction is written:



The atomic numbers (number of protons) for radium, polonium and helium (the alpha particles) are 88, 84 and 2, respectively. Note that the atomic numbers and atomic mass numbers balance on the two sides of this equation. Note that the atomic mass decreased by 4 due to the loss of two neutrons and two protons, and the atomic number decreased by 2 due to the loss of two protons.

Beta decay causes the atomic number to increase by one. Beta decay can be described as a neutron in the nucleus converted to a proton. An example of beta decay is radium-228 which decays to actinium. This reaction is written:



The atomic numbers are 88 for Ra and 89 for Ac (the beta decay described here is the negative kind). The atomic numbers and atomic mass numbers balance in this equation since the atomic number for an electron is -1 and its atomic mass number is zero. Gamma decay changes neither the atomic number nor the element; it only involves a loss of energy.

Not all atoms are equally stable and different isotopes characteristically decay at different rates. The concept of half life is used to quantitatively describe these differences. The half life of an isotope is the time required for one half of the atoms present to decay. Half lives can range from

billions of years or more (the half life of uranium-238 is 4.5×10^9 years) to millionths of a second (the half life of polonium-214 is 164×10^{-6} sec) and even less. For example, the half lives of radon-219 and radon-220 are too short to survive transport through a drinking water distribution system.

Atomic fission occurring in a nuclear reactor can also contribute radioactivity to drinking water, if by-products are released. This process, the source of immense energy, is triggered by adding a neutron to certain nuclei. The phenomenon occurs for heavy nuclei, the classical examples being isotopes of uranium (uranium-235) and plutonium (plutonium-239). When a neutron is added, each of these isotopes breaks into two roughly equal parts. Each of the parts (called fission fragments) is itself a radioactive nucleus and decays through a sequence of isotopes by beta and gamma decay.

Generally units such as mg/l, micrograms/liter or ppm are used to describe the concentrations in drinking water of pollutants, toxic and hazardous substances. However, certain unique properties of radioactive substances limit the utility of these units and alternative units are used to directly compare the health effects of different radionuclides.

Two important concepts are needed to describe radioactivity:

- How many nuclear transformations occur per second.
- How much radiation or how much energy is imparted to tissue (called absorbed dose). Energy is related to the number of particles emitted by the radioisotope, per second, and their energies.

Damage from radionuclides depends on the radiation emitted (alpha, beta or gamma) and not the mass of the radionuclides. Thus it is essential to have a unit that describes the number of radioactive emissions per time period, or activity. The activity is related to the half life: Longer half lives mean lower activity. Historically by definition one gram of radium is said to have 1 curie (1 Ci) of activity. By comparison, 1 gm of uranium-238 has an activity of 0.36 millionth of a curie. One curie is equivalent to 3.7×10^{10} disintegrations per second. The International System (SI) unit for activity is the Becquerel (Bq) which is equal to one disintegration/second.

The effect of radioactivity depends not only on the activity (decays/time) but on the kind of radiation (alpha, beta or gamma) and its energy. These two properties determine the absorbed dose to tissue when decay occurs internally and the internal organs are the target.

A common unit of absorbed dose is called the rad, and one rad is equivalent to one hundred ergs (metric unit of energy) in one gram of matter (for perspective on the size of an erg, 10 million erg/sec is one watt). In general, these units are quite large and engineering shorthand is used to describe the activities. Shown below are some commonly used prefixes.

Greek, prefix & abbreviation	Value	Shorthand exponential notation	Description
mill—m.....	1/1,000	10 ⁻³	One part per thousand.
micro—Greek m.....	1/1,000,000	10 ⁻⁶	One part per million.
nano—n.....	1,1,000,000,000	10 ⁻⁹	One part per billion.
pico—p.....	1/1,000,000,000,000	10 ⁻¹²	
fermi—f.....	1/1,000,000,000,000,000	10 ⁻¹⁵	
atto—a.....	1/1,000,000,000,000,000,000	10 ⁻¹⁸	

Thus 1 picocurie is a millionth millionth of a curie and is abbreviated 1 pCi. Also 1 millirad (1 mrad) is one thousandth of a rad.

Because of the particle mass and charge, 1 rad deposited in tissue by alpha particles creates a more concentrated biological damage than 1 rad of gamma rays. To compensate for this difference in damage and subsequent effect, a new unit was created—the rem. This is called the dose equivalent. The absorbed dose is measured in rads and the dose equivalent is measured in rems.

The rad and rem are related by a quality factor as follows:

Number of rems = Q times the number of rads

Where Q is the quality factor which has been assigned the following value:

Q=1 for beta particles and all electromagnetic radiations (gamma rays and x-rays)

Q=10 for neutrons from spontaneous fission and for protons

Q=20 for alpha particles and fission fragments

The quality factor is meant to approximately account for the relative harm caused by various types of radiation. The International System (SI) unit corresponding to the rem is the Sievert (Sv). One Sievert equals 100 rem.

APPENDIX B—BETA PARTICLE AND PHOTON EMITTERS

Nuclide	Ch (pCi/liter)
H-3.....	6.09E+04
BE-7.....	4.35E+04
N-13.....	1.52E+05
C-11.....	9.92E+04
C-14.....	3.20E+03
C-15.....	6.69E+06
O-15.....	4.95E+05
F-18.....	3.95E+04
NA-22.....	4.66E+02
NA-24.....	3.35E+03
SI-31.....	1.02E+04
P-32.....	6.41E+02
P-33.....	1.87E+03
S-35.....	1.29E+04
CL-36.....	1.85E+03
CL-38.....	2.12E+04
K-42.....	3.90E+03
CA-45.....	1.73E+03
CA-47.....	8.46E+02
SC-46.....	8.63E+02
SC-47.....	2.44E+03
SC-48.....	7.66E+02
V-48.....	6.44E+02
CR-51.....	3.80E+04
MN-52.....	7.33E+02
MN-54.....	2.01E+03
MN-56.....	5.64E+03
FE-55.....	9.25E+03

APPENDIX B—BETA PARTICLE AND PHOTON EMITTERS—Continued

Nuclide	Ch (pCi/liter)
FE-59.....	8.44E+02
CO-57.....	4.87E+03
CO-58.....	1.59E+03
CO-58M.....	6.49E+04
CO-60.....	2.18E+02
NI-59.....	2.70E+04
NI-63.....	9.91E+03
NI-65.....	8.81E+03
CU-64.....	1.19E+04
ZN-65.....	3.96E+02
ZN-69.....	6.31E+04
ZN-69M.....	4.22E+03
GA-67.....	7.02E+03
GA-72.....	1.19E+03
GE-71.....	4.36E+05
AS-73.....	7.85E+03
AS-74.....	1.41E+03
AS-76.....	1.06E+03
AS-77.....	4.33E+03
SE-75.....	5.74E+02
BR-82.....	3.15E+03
RB-82.....	4.36E+05
RB-86.....	4.85E+02
RB-87.....	5.01E+02
RB-88.....	2.91E+04
RB-89.....	5.27E+04
SR-82.....	2.41E+02
SR-85.....	2.83E+03
SR-85M.....	2.37E+05
SR-89.....	5.99E+02
SR-90.....	4.20E+01
SR-91.....	2.16E+03
SR-92.....	3.10E+03
Y-90.....	5.10E+02
Y-91.....	5.76E+02
Y-91M.....	1.32E+05
Y-92.....	2.87E+03
Y-93.....	1.20E+03
ZR-93.....	5.09E+03
ZR-95.....	1.46E+03
ZR-97.....	6.50E+02
NB-93M.....	1.05E+04
NB-94.....	7.07E+02
NB-95.....	2.15E+03
NB-95M.....	2.39E+03
NB-97.....	2.35E+04
NB-97M.....	1.37E+06
MO-99.....	1.83E+03
TC-95.....	6.97E+04
TC-95M.....	3.12E+03
TC-96.....	2.05E+03
TC-96M.....	1.76E+05
TC-97.....	3.25E+04
TC-97M.....	4.45E+03
TC-99.....	3.79E+03
TC-99M.....	8.96E+04
RU-97.....	7.96E+03
RU-103.....	1.81E+03
RU-105.....	4.99E+03
RU-106.....	2.03E+02
RH-103M.....	4.71E+05
RH-105.....	3.72E+03
RH-105M.....	5.51E+06

APPENDIX B—BETA PARTICLE AND PHOTON EMITTERS—Continued

Nuclide	Ch (pCi/liter)
RH-106.....	1.24E+06
PD-100.....	1.30E+03
PD-101.....	1.34E+04
PD-103.....	6.94E+03
PD-107.....	3.66E+04
PD-109.....	2.12E+03
AG-105.....	2.70E+03
AG-108.....	6.26E+05
AG-108M.....	7.23E+02
AG-109M.....	1.67E+07
AG-110.....	1.84E+06
AG-110M.....	5.12E+02
AG-111.....	1.08E+03
CD-109.....	2.27E+02
CD-115.....	9.58E+02
CD-115M.....	3.39E+02
IN-113M.....	5.24E+04
IN-114.....	9.76E+05
IN-114M.....	3.23E+02
IN-115.....	3.51E+01
IN-115M.....	1.64E+04
SN-113.....	1.74E+03
SN-121.....	6.06E+03
SN-121M.....	2.26E+03
SN-125.....	4.46E+02
SN-126.....	2.93E+02
SB-122.....	8.10E+02
SB-124.....	5.63E+02
SB-125.....	1.94E+03
SB-126.....	5.44E+02
SB-126M.....	5.85E+04
SB-127.....	8.18E+02
SB-129.....	3.09E+03
TE-125M.....	1.49E+03
TE-127.....	7.92E+03
TE-127M.....	6.63E+02
TE-129.....	2.72E+04
TE-129M.....	5.24E+02
TE-131.....	2.68E+04
TE-131M.....	9.71E+02
TE-132.....	5.80E+02
I-122.....	2.11E+05
I-123.....	1.07E+04
I-125.....	1.51E+02
I-126.....	8.10E+01
I-129.....	2.10E+01
I-130.....	1.19E+03
I-131.....	1.08E+02
I-132.....	8.19E+03
I-133.....	5.49E+02
I-134.....	2.14E+04
I-135.....	2.34E+03
CS-131.....	2.28E+04
CS-134.....	8.13E+01
CS-134M.....	1.01E+05
CS-135.....	7.94E+02
CS-136.....	5.18E+02
CS-137.....	1.19E+02
CS-138.....	2.56E+04
BA-131.....	2.95E+03
BA-133.....	1.52E+03
BA-133M.....	2.62E+03
BA-137M.....	2.15E+06

APPENDIX B—BETA PARTICLE AND
PHOTON EMITTERS—Continued

Nuclide	Ch (pCi/liter)
BA-139	1.38E+04
BA-140	5.82E+02
LA-140	6.52E+02
CE-141	1.89E+03
CE-143	1.21E+03
CE-144	2.61E+02
PR-142	1.04E+03
PR-143	1.17E+03
PR-144	4.70E+04
PR-144M	1.12E+05
ND-147	1.25E+03
ND-149	1.17E+04
PM-147	5.24E+03
PM-148	5.05E+02
PM-148M	5.75E+02
PM-149	1.38E+03
SM-151	1.41E+04
SM-153	1.83E+03
EU-152	8.41E+02
EU-154	5.73E+02
EU-155	3.59E+03
EU-156	6.00E+02
GD-153	4.68E+03
GD-159	2.76E+03
TB-158	1.25E+03
TB-160	8.15E+02
DY-165	1.51E+04
DY-166	8.30E+02
HO-166	9.81E+02
ER-169	3.64E+03
ER-171	3.80E+03
TM-170	1.03E+03
TM-171	1.27E+04
YB-169	1.83E+03
YB-175	3.11E+03
LU-177	2.55E+03
HF-181	1.17E+03
TA-182	8.42E+02
W-181	1.90E+04
W-185	3.44E+03
W-187	2.66E+03
RE-183	5.40E+03
RE-186	1.88E+03
RE-187	5.82E+05
RE-188	1.79E+03
OS-185	2.46E+03
OS-191	2.38E+03
OS-191M	1.43E+04
OS-193	1.69E+03
IR-190	1.01E+03
IR-192	9.57E+02
IR-194	1.04E+03
PT-191	3.81E+03
PT-193	4.61E+04
PT-193M	3.02E+03
PT-197	3.40E+03
PT-197M	1.75E+04
AU-196	3.66E+03
AU-198	1.31E+03
HG-197	5.76E+03
HG-203	2.39E+03
TL-202	3.84E+03
TL-204	1.68E+03
TL-207	4.00E+05
TL-208	2.83E+05
TL-209	3.58E+05
PB-203	5.06E+03
PB-209	2.53E+04
PB-210	1.01E+00
PB-211	1.28E+04
PB-212	1.23E+02
PB-214	1.18E+04
BI-206	6.56E+02
BI-207	1.01E+03
BI-212	5.20E+03
BI-213	1.50E+04
BI-214	1.89E+04
FR-223	3.41E+03

APPENDIX B—BETA PARTICLE AND
PHOTON EMITTERS—Continued

Nuclide	Ch (pCi/liter)
RA-225	9.14E+00
RA-228	7.85E+00
AC-227	1.27E+00
AC-228	3.27E+03
TH-231	4.07E+03
TH-234	4.01E+02
PA-233	1.51E+03
PA-234	2.56E+03
PA-234M	9.30E+05
U-237	1.78E+03
U-240	1.54E+03
NP-236	5.96E+03
NP-238	1.39E+03
NP-239	1.68E+03
NP-240	2.31E+04
NP-240M	1.74E+05
PU-241	6.26E+01
PU-243	1.64E+04
AM-242M	1.27E+00

Ch=Concentration in water for 4 mrem ede/y,
assuming 2 liters daily intake.

APPENDIX C—ALPHA EMITTERS

NUCLIDE	Cm (pCi/liter)	Ci (pCi/liter)
SM-147	1.06E+02	1.04E+02
BI-210	1.94E+03	1.01E+03
BI-211	2.05E+05	1.56E+05
PO-210	1.40E+01	7.46E+00
PO-212	1.15E+14	8.78E+13
PO-213	8.03E+12	6.06E+12
PO-214	2.43E+11	1.86E+11
PO-215	9.17E+09	6.84E+09
PO-216	7.38E+07	5.30E+07
PO-218	9.50E+04	6.91E+04
AT-217	5.74E+08	4.27E+08
FR-221	4.50E+04	3.26E+04
RA-223	3.21E+01	2.41E+01
RA-224	5.46E+01	4.06E+01
RA-226	2.07E+01	1.57E+01
AC-225	1.85E+02	1.13E+02
TH-227	6.62E+02	4.03E+02
TH-228	1.53E+02	1.25E+02
TH-229	5.15E+01	4.93E+01
TH-230	8.27E+01	7.92E+01
TH-232	9.18E+01	8.80E+01
PA-231	1.02E+01	1.02E+01
U-232	1.02E+01	5.72E+00
U-233	2.56E+01	1.38E+01
U-234	2.59E+01	1.39E+01
U-235	2.65E+01	1.45E+01
U-236	2.74E+01	1.47E+01
U-238	2.62E+01	1.46E+01
NP-237	7.19E+00	7.06E+00
PU-236	3.33E+01	3.23E+01
PU-238	7.15E+00	7.02E+00
PU-239	6.49E+01	6.21E+01
PU-240	6.49E+01	6.22E+01
PU-242	6.83E+01	6.54E+01
PU-244	7.02E+00	6.87E+00
AM-241	6.45E+00	6.34E+00
AM-242	8.66E+03	5.34E+03
AM-243	6.49E+00	6.37E+00
CM-242	1.45E+02	1.33E+02
CM-243	8.47E+00	8.30E+00
CM-244	1.00E+01	9.84E+00
CM-245	6.35E+00	6.23E+00
CM-246	6.38E+00	6.27E+00
CM-247	6.93E+00	6.79E+00
CM-248	1.71E+00	1.67E+00
CF-252	1.70E+01	1.62E+01

Cm=Concentration in water for lifetime mortality
risk=1×10⁻⁴
Ci=Concentration in water for lifetime incidence
risk=1×10⁻⁴
Both assume 2 liters daily intake of water.

List of Subjects in 40 CFR Parts 141 and
142

Chemicals, Reporting and record
keeping requirements, Water supply,
Administrative practice and procedure.

Dated: June 17, 1991.

William K. Reilly,
*Administrator, Environmental Protection
Agency.*

For the reasons set forth in the
preamble, title 40 of the Code of Federal
Regulations is proposed to be amended
as follows:

**PART 141—NATIONAL PRIMARY
DRINKING WATER REGULATIONS**

1. The authority citation for part 141
continues to read as follows:

Authority: 42 U.S.C. 300f, 300g-1, 300g-2,
300g-3, 300g-4, 300g-5, 300g-6, 300j-4 and
300j-9.

2. Section 141.2 is amended by adding,
in alphabetical order, a definition for
"adjusted gross alpha" as follows:

§ 141.2 Definitions

* * * * *

Adjusted gross alpha: Adjusted gross
alpha is defined as the result of a gross
alpha measurement, less radium-226 and
less uranium. Radon is not included in
adjusted gross alpha.

* * * * *

3. Section 141.15 is amended by
revising the introductory text to read as
follows:

**§ 141.15 Maximum contaminant levels for
radium-226, radium-228, and gross alpha
particle radioactivity in community water
systems.**

The following are the maximum
contaminant levels for radium-226,
radium-228, and gross alpha particle
radioactivity, which shall remain
effective until [insert date 18 months
after publication of the final rule in the
Federal Register];

* * * * *

4. Section 141.16 is proposed to be
amended by adding introductory text to
read as follows:

**§ 141.16 Maximum contaminant levels for
beta particle and photon radioactivity from
man-made radionuclides in community
water systems.**

The following maximum contaminant
levels shall remain effective until [insert
date 18 months after publication of the
final rule in the **Federal Register**];

* * * * *

5. Section 141.25 is amended by
revising the section to read as follows:

§ 141.25 Sampling and analytical methods for radionuclides.

The current analytical methods outlined in § 141.25 and the monitoring requirements in § 141.26 shall remain effective until [insert date 18 months after promulgation of the final rule]. After that date, the monitoring and analytical methods specified below will be effective. Community water systems and non-transient, non-community water systems shall conduct monitoring to determine compliance with the maximum contaminant levels specified in § 141.64 in accordance with this section.

(a) Monitoring shall be conducted as follows:

(1) Groundwater systems shall take a minimum of one sample at every entry point to the distribution system which is representative of each well after treatment (hereafter called a sampling point) beginning in the compliance period starting January 1, 1996. The system shall take each sample at the same sampling point unless conditions make another sampling point more representative of each source or treatment plant.

(2) Surface water systems shall take a minimum of one sample at every entry point to the distribution system after any application of treatment or in the distribution system at a point which is representative of each source after treatment (hereafter called a sampling point) beginning in the compliance period starting January 1, 1996. The system shall take each sample at the same sampling point unless conditions make another sampling point more representative of each source or treatment plant.

(3) If a system draws water from more than one source and the sources are combined before distribution, the system must sample at an entry point to the distribution system during periods of normal operating conditions (i.e., when water is representative of all sources being used).

(4) The State may reduce the total number of samples which must be analyzed by allowing the use of compositing, except for radon and gross beta samples, which may not be composited.

(i) Composite samples from a maximum of five sampling points within one system are allowed. Compositing of samples must be done in the laboratory.

(ii) If the concentration in the composite sample is greater than or equal to 3 pCi/l of any radionuclide, the individual non-composited samples, or if these are not available, follow-up samples must be analyzed to identify the sampling points which may violate

one of the MCLs. Any follow-up samples must be taken within 14 days at each sampling point included in the composite. Samples must be analyzed for the contaminants which were detected in the composite sample.

(5) The frequency of monitoring for radon shall be in accordance with paragraph (b) of this section; the frequency of monitoring for radium-226, radium-228, uranium, and adjusted gross alpha shall be in accordance with paragraph (c) of this section; and the frequency of monitoring for beta and photon emitters shall be in accordance with paragraph (d) of this section.

(b) The frequency of monitoring conducted to determine compliance with the maximum contaminant level for radon specified in § 141.64 shall be conducted as follows:

(1) Groundwater systems or systems using both ground and surface water are required to take four consecutive quarterly samples during the first year of each three-year compliance period of each nine-year compliance cycle. Annual samples are required in the second and third years of each compliance period. The initial monitoring for radon must be completed by January 1, 1999.

(2) Surface water systems are not required to monitor for radon. The State may require it.

(3) The State may grant a waiver to ground water systems or systems that use both ground and surface water for monitoring requirements in paragraph (b)(1) of this section, provided that they have monitored quarterly in the initial year, and completed annual testing in the second and third year of the first compliance period (at least one sample shall have been taken since January 1, 1990). Groundwater systems shall demonstrate that all previous analytical results were less than the maximum contaminant level. Systems that use a new water source are not eligible for a waiver until 4 quarters of monitoring and two subsequent years of a single annual sample of the new source has been completed.

(4) The State may grant a waiver if the State determines that the system is reliably and consistently below the MCL, based on a consideration of the following factors:

(i) Potential radon contamination of the water source due to the geological characteristics of the area where the water source is located.

(ii) Previous analytical results.

(5) A condition of the waiver shall require that a system take a minimum of 1 sample every three-year compliance period.

(6) A waiver remains in effect until the completion of the nine-year compliance cycle. Systems not receiving a waiver must monitor in accordance with the provisions of paragraph (b)(1) of this section.

(7) A decision by the State to grant a waiver shall be made in writing and shall set forth the basis for the determination. The determination may be initiated by the State or upon an application by the public water system. The public water system shall specify the basis for its request. The State shall review and, where appropriate, revise its determination of appropriate frequency.

(8) A system which exceeds the maximum contaminant level in § 141.64 of this part shall monitor quarterly beginning in the next quarter after the violation occurred. Quarterly monitoring must continue until the average of 4 consecutive quarterly samples is below the MCL.

(9) If monitoring data collected after January 1, 1990 are generally consistent with the requirements of § 141.25, then the State may allow systems to use those data to satisfy the monitoring requirement for the initial compliance period.

(c) The frequency of monitoring conducted to determine compliance with the maximum contaminant levels in § 141.64 for radium-226, radium-228, uranium, and adjusted gross alpha shall be as follows:

(1) Groundwater systems, surface water systems and systems using both ground and surface water shall take one sample annually at each sampling point during each compliance period starting in the compliance period beginning January 1, 1996. If all samples are less than the MCL, then monitoring can be reduced to one sample per compliance period, in accordance with paragraphs (c) (2) through (6) of this section.

(2) Systems may apply to the State for a waiver from the monitoring frequencies specified in paragraph (c)(1) of this section, if they have completed the required three annual samples in the first three-year compliance period. Systems that use a new water source are not eligible for a waiver until three years of monitoring of the new source has been completed.

(3) The State may grant a waiver if it finds that the system is reliably and consistently below the MCL, based on a consideration of the following factors:

(i) Potential contamination of the water source; and

(ii) Previous analytical results.

(4) A condition of the waiver shall require that a system take a minimum of

one sample during the effective period of the waiver. The term during which the waiver is effective shall not exceed one nine-year compliance cycle.

(5) The State may grant a waiver provided water systems have monitored annually for at least three consecutive years. (At least one sample shall have been taken since January 1, 1990.) Both surface and groundwater systems shall demonstrate that all previous analytical results were less than the maximum contaminant level. Systems that use a new water source are not eligible for a waiver until three consecutive annual samples from the new source have been collected and analyzed.

(6) A decision by the State to grant a waiver shall be made in writing and shall set forth the basis for the determination. The determination may be initiated by the State or upon an application by the public water system. The public water system shall specify the basis for its request. The State shall review and, where appropriate, revise its determination of the appropriate monitoring frequency when the system submits new monitoring data or when other data relevant to the system's appropriate monitoring frequency become available.

(7) Systems which exceed the maximum contaminant levels in § 141.64 of this part shall monitor quarterly beginning in the next quarter after the violation occurred. Quarterly monitoring must continue until 4 consecutive quarterly samples are below the MCL.

(8) If monitoring data collected after January 1, 1985 are generally consistent with the requirements of § 141.25, then the State may allow systems to use these data to satisfy the monitoring requirements for the initial compliance period beginning January 1, 1996, except at least one sample shall have been collected since January 1, 1990.

(d) The frequency of monitoring conducted to determine compliance with the maximum contaminant levels in § 141.64 for beta and photon emitters shall be as follows:

(1) Only systems (both surface and ground water) determined by the State to be vulnerable need to sample for beta and photon emitters. Vulnerability shall be based on the proximity of the water source(s) to facilities using or producing radioactive materials. Vulnerable systems shall monitor quarterly for beta and annually for tritium and strontium, beginning in the compliance period starting January 1996. Systems must

begin monitoring within one quarter after being notified by the State that the system is vulnerable. Existing vulnerability determinations by the State shall remain effective until the State reviews and either reaffirms them or revises them.

(2) Systems determined to be vulnerable may not apply to the State for a waiver from the monitoring frequencies specified in paragraph (d)(1) of this section.

(3) If the gross beta particle activity exceeds 50 pCi/l, an analysis of the sample must be performed to identify the major radioactive constituents present in the sample and the appropriate doses shall be calculated and summed to determine compliance with § 141.64, using appendix B, [insert citation for final Federal Register]. Measured levels of tritium and strontium shall be included in this calculation. Doses shall also be calculated and combined for measured levels of tritium and strontium to determine compliance.

(4) Suppliers of water shall conduct additional monitoring as directed by the State, to determine the concentration of man-made radioactivity in principal watersheds designated by the State.

(5) Vulnerable systems which exceed the maximum contaminant levels in § 141.64 shall monitor monthly beginning in the next month after the violation occurred. Monthly monitoring shall continue until the system has established, by a rolling average of 3 monthly samples, that the MCL is being met.

(e) Confirmation samples:

(1) Where the results of sampling for radon, radium-226, radium-228, adjusted gross alpha, uranium, and beta and photon emitters indicate an exceedence of the maximum contaminant level, the State may require that one additional sample be collected as soon as possible after the initial sample was taken (but not to exceed two weeks) at the same sampling point.

(2) If a State-required confirmation sample is taken for any contaminant, then the results of the initial and confirmation sample shall be averaged. The resulting average shall be used to determine the system's compliance in accordance with paragraph (h) of this section. States have the discretion to delete results of obvious sampling or analytic errors.

(f) The State may require more frequent monitoring than specified in paragraphs (b), (c), and (d) of this

section or may require confirmation samples for positive and negative results at its discretion.

(g) Systems may apply to the State to conduct more frequent monitoring than the minimum monitoring frequencies specified in this section.

(h) Compliance with §§ 141.15, 141.16, and 141.64 (as appropriate) shall be determined based on the analytical result(s) obtained at each sampling point.

(1) For systems which are conducting monitoring at a frequency greater than annual, compliance with the maximum contaminant levels for radon, radium-226, radium-228, adjusted gross alpha, uranium, and beta and photon emitters is determined by a running annual average at each sampling point. If the average at any sampling point is *greater* than the MCL, then the system is out of compliance. If any one sample would cause the annual average to be exceeded, then the system is out of compliance immediately. Any sample below the detection limit shall be calculated at one-half the detection limit for the purpose of determining the annual average.

(2) For systems which are monitoring annually, or less frequently, the system is out of compliance with the maximum contaminant levels for radon, radium-226, radium-228, adjusted gross alpha, uranium, and beta and photon emitters if the level of a contaminant at any sampling point is greater than the MCL. If a confirmation sample is required by the State, the determination of compliance will be based on the average of the two samples.

(3) If a public water system has a distribution system separable from other parts of the distribution system with no interconnections, only those parts of the system that exceed the MCL need to conduct increased monitoring.

(4) If a public water system has a distribution system separable from other parts of the distribution system with no interconnections, the State may allow the system to give public notice to only the area served by that portion of the system which is out of compliance.

(i) Each public water system shall monitor at the time designated by the State during each compliance period.

(j) Radionuclides analysis:

(1) Analysis for radon, radium-226, radium-228, adjusted gross alpha, uranium, and beta and photon emitters shall be conducted using the following methods:

PROPOSED METHODOLOGY FOR RADIONUCLIDE CONTAMINANTS

Contaminant	Methodology	Reference (method or page number)								
		EPA ¹	EPA ²	EPA ³	EPA ⁴	SM ⁵	ASTM ⁶	USGS ⁷	DOE ⁸	Other
Naturally occurring										
Gross alpha and beta.	Evaporation	900.0	pp. 1-3.....	00-01....	p. 1	7110 B.....	D 1943-81	R-1120-76.....		
Gross alpha	Co-precipitation			00-02.....						
Radium 226	Radon emanation.	903.1	pp. 16-23.....	Ra-03	p. 19	7500-Ra B	D 3454-86	R-1141-76.....		N.Y. ⁹
	Radiochemical.....	903.0		Ra-05						
Radium 228	Radiochemical.....	904.0	pp. 24-28.....	Ra-05	p. 19	7500-Ra D*		R-1142-76.....		N.Y. ⁹
Radon 222	Liquid scintillation.									N.J. ¹⁰
	Lucas cell.....									913 ¹¹
Uranium.....	Radiochemical.....	908.0				7500-U B	D 3972-82			LS ¹²
	Fluorometric.....	908.1				7500-U C	D 2907-83	R-1180-76.....	E-U-03.....	LC ¹²
	Alpha spectrometry.			00-07....	p. 33			R-1181-76.....	E-U-04.....	
								R-1182-76.....		
Man-made										
Radioactive cesium.	Precipitation	901.0	pp. 4-5.....			7500-Cs B		R-1110-87.....	E-Cs-01.....	
Radioactive iodine.	Precipitation	902.0		I-01		7500-I B	D 2334-88			
Radioactive strontium 89, 90.	Precipitation	905.0	pp. 29-33.....		p. 65	7500-Sr B		R-1160-76.....		
	Radiochemical.....		pp. 108-114	Sr-04.....					E-Sr-01.....	
Tritium.....	Liquid scintillation.	906.0	pp. 34-40.....	H-02.....	p. 87	7500-3H B	D 2476-81 (87)	R-1171-76.....		
Gamma and photon emitters.	Gamma ray Spectrometry.	901.1					D-3649-85.....		4.5.2.3.....	

¹ "Prescribed Procedures for Measurement of Radioactivity in Drinking Water," EPA Environmental Monitoring and Support Laboratory, Cincinnati, OH (EPA-600/4-80-032, August 1980. (EPA, 1980).

² "Interim Radiochemical Methodology for Drinking Water," EPA-600/4-75-008, March 1976. (EPA, 1976)

³ Eastern Environmental Radiation Facility, Montgomery, AL 36109, "Radiochemical Procedures Manual," EPA 520/5-84-006, August 1984. (EPA, 1984a).

⁴ "Radiochemical Analytical Procedures for Analysis of Environmental Samples," EMSL-LV-0539-17, March 1979. (EPA, 1976b).

⁵ "Standard Methods for the Examination of Water and Wastewater," 17th edition, American Public Health Association, American Water Works Association, Water Pollution Control Federation, 1989. (APHA, 1989).

⁶ 1989 Annual Book of ASTM Standards, Vol. 11.02, American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103. (ASTM, 1989)

⁷ Methods for Determination of Radioactive Substances in Water and Fluvial Sediments," Book 5, 1989, Techniques of Water-Resources Investigations of the United States Geological Survey, Chapter A5. (USGS, 1989).

⁸ Environmental Measurements Laboratory, U.S. Department of Energy, "EML PROCEDURES MANUAL, 27th edition." (DOE, 1990).

⁹ "Determination of ²²⁶Ra and ²²⁸Ra (Ra-02), Radiological Sciences Institute Center for Research—New York State Department of Health, January 1980 (Revised June 1982). (NY State DOH, 1982).

¹⁰ "Determination of Radium 226 in Drinking Water," State of New Jersey—Department of Environmental Protection—Division of Environmental Quality—Bureau of Radiation and Inorganic Analytical Services, August 1990. (NJ DEQ, 1990).

¹¹ Method 913—Radon in drinking water by liquid scintillation, Environmental Monitoring and Support Laboratory, Las Vegas, NV. (EPA 1991q).

¹² Appendix D, Analytical Test Procedure, "The Determination of Radon in Drinking Water," p. 22, Two Test Procedures for Radon in Drinking Water, Interlaboratory Collaborative Study, EPA/600/2-87/082, March 1987. (EPA, 1987e).

(2) Sample collection for radon, radium-226, radium-228, adjusted gross alpha, uranium, and beta and photon

emitters under this section shall be conducted using the sample preservation, container, and maximum

holding time procedures specified in the table below:

Sampling handling, preservation, holding times		Container ²	Maximum holding time ³
Parameter	Preservative ¹		
Gross alpha	Conc. HCl or HNO ₃ to pH <2 ⁴	P or G.....	6 months.
Gross beta	Conc. HCl or HNO ₃ to pH <2 ⁴	P or G.....	6 months.
Radium-226	Conc. HCl or HNO ₃ to pH <2	P or G.....	6 months.
Radium-228	Conc. HCl or HNO ₃ to pH <2	P or G.....	6 months.
Radon-222 ⁵	Cool 4°C.	Glass with Teflon-lined septum.....	4 days
Uranium natural	Conc. HCl or HNO ₃ to pH <2	P or G.....	6 months.
Radioactive Cesium	Conc. HCl to pH <2	P or G.....	6 months.
Radioactive Strontium	Conc. HCl or HNO ₃ to pH <2	P or G.....	6 months.
Radioactive Iodine	None	P or G.....	6 months.
Tritium	None	G.....	6 months.
Photon emitters	Conc. HCl or HNO ₃ to pH <2	P or G.....	6 months.

¹ (All except radon-22 samples). It is recommended that the preservative be added to the sample at the time of collection unless suspended solids activity is to be measured. However, if the sample must be shipped to a laboratory or storage area, acidification of the sample (in its original container) may be delayed for a period not to exceed 5 days. A minimum of 16 hours must elapse between acidification and analysis.

² P=Plastic, hard or soft; G=Glass, hard or soft.

³ Holding time is defined as the period from time of sampling to time of analysis. In all cases, samples should be analyzed as soon after collection as possible.

⁴ If HCl is used to acidify samples which are to be analyzed for gross alpha or gross beta activities, the acid salts must be converted to nitrate salts before transfer of the samples to planchets.

⁵ The procedure of a positive pressure collection in 60-ml glass bottles is to be followed. This procedure is described in appendix C, NIRS Sampling Instructions—Radon, p. 26, Two Test Procedures For Radon In Drinking Water, Interlaboratory Collaborative Study, EPA/600/2-87/082, March 1987.

(3) Analysis under this section shall only be conducted by laboratories that have received approval by EPA or the State. To receive approval to conduct analyses for radon, radium-226, radium-228, adjusted gross alpha, uranium, and beta and photon emitters the laboratory must:

(i) Analyze Performance Evaluation samples which include those substances provided by EPA Environmental Monitoring and Support Laboratory or equivalent samples provided by the State.

(ii) Achieve quantitative results on the analyses that are within the following acceptance limits:

Contaminant	Acceptance Limits ¹
Radium-226.....	±30% at ≥ 5 pCi/l.
Radium-228.....	±50% at ≥ 5 pCi/l.
Uranium.....	±30% at ≥ 5 pCi/l.
Radon-222 ²	±30% at ≥ 300 pCi/l.
Gross alpha emitters.....	±50% at ≥ 15 pCi/l.
Gross beta emitters.....	±30% at ≥ 30 pCi/l.
Radioactive Cesium.....	±30% at ≥ 10 pCi/l.
Radioactive Iodine.....	±20% at ≥ 20 pCi/l.
Radioactive Strontium total, 89 and 90.....	±30% at ≥ 5 pCi/l.
Trilium.....	±20% at ≥ 1200 pCi/l.

¹ Acceptance limits based on 100 minute count.

² Radon acceptance limits based on 4 day elapsed time from sample collection to analysis.

6. Section § 141.32 is amended by adding paragraphs (e)(77) through (82), to read as follows:

§ 141.32 Public notification.

* * * * *

(e) * * *

(77) *Radon*: The United States Environmental Protection Agency (EPA) sets drinking water standards and has determined that radon is of health concern at certain levels of exposure. Radon is a naturally occurring radioactive contaminant that occurs in ground water. It is a gas, and is released from water into household air during water use. Radon has been found in epidemiology studies to cause lung cancer in humans at high exposure levels; at lower exposure levels the risk of lung cancer is reduced. EPA has set the drinking water standard for radon in public water supplies at 300 picocuries per liter (pCi/l) to protect against lung cancer risk. Drinking water that meets the EPA standard is associated with little of this risk and is considered safe for radon.

(78) *Radium 226*: The United States Environmental Protection Agency (EPA) sets drinking water standards and has

determined that radium 226 is of health concern at certain levels of exposure. Radium 226 is a naturally occurring radioactive contaminant that occurs primarily in ground water. Radium 226 has been found in epidemiology studies to cause bone cancer in humans at high exposure levels, and is believed to cause other cancers as well; at lower exposure levels the risk of cancer is reduced. EPA has set the drinking water standard for radium 226 at 20 picocuries per liter (pCi/l) to protect against cancer risk. Drinking water that meets the EPA standard is associated with little of this risk and is considered safe for radium 226.

(79) *Radium 228*: The United States Environmental Protection Agency (EPA) sets drinking water standards and has determined that radium 228 is of health concern at certain levels of exposure. Radium 228 is a naturally occurring radioactive contaminant that occurs primarily in ground water. Radium 228 has been found in epidemiology studies to cause bone cancer in humans at high exposure levels and is believed to cause other cancers as well; at lower exposure levels the risk of bone cancer is reduced. EPA has set the drinking water standard for radium 228 and 20 picocuries per liter (pCi/l) to protect against cancer risk. Drinking water that meets the EPA standard is associated with little of this risk and is considered safe for radium.

(80) *Uranium*: The United States Environmental Protection Agency (EPA) sets drinking water standards and has determined that uranium is of health concern at certain levels of exposure. Uranium is a naturally occurring radioactive contaminant that occurs in both ground and surface water. Uranium is believed to cause bone cancer and other cancers in humans at high exposure levels; at lower exposure levels the risk of cancer is reduced. EPA also believes uranium can be toxic to the kidneys. EPA has set the drinking water standard for uranium at 20 micrograms per liter (µg/l) to protect against both cancer risk and risk of kidney damage. Drinking water that meets the EPA standard is associated with little of this risk and is considered safe for uranium.

(81) *Gross Alpha*: The United States Environmental Protection Agency (EPA) sets drinking water standards and has determined that alpha emitting radionuclides may be of health concern at certain levels of exposure. Alpha

emitters are primarily naturally occurring radioactive contaminants, but several derive from man-made sources. They may occur in either ground or surface water. Alpha emitters are believed to cause cancer in humans at high exposure levels because they emit ionizing radiation. At lower levels, the risk of cancer is reduced. EPA has set the drinking water standard for alpha emitters at 15 picocuries per liter (pCi/l) to protect against cancer risk. Drinking water that meets the EPA standard is associated with little of this risk and is considered safe for alpha emitters.

(82) *Beta and photon emitters*: The United States Environmental Protection Agency (EPA) sets drinking water standards and has determined that beta and photon emitting radionuclides may be of health concern at certain levels of exposure. Beta and photon emitters are primarily man-made radioactive contaminants associated with the operation of nuclear power facilities, facilities using radioactive material for research or manufacturing, or facilities where these materials are disposed. Some beta emitters are naturally occurring. Beta and photon emitters are expected to occur primarily in surface water. Beta and photon emitters are believed to cause cancer in humans at high exposure levels because they emit ionizing radiation. At lower levels, the risk of cancer is reduced. EPA has set the drinking water standard for beta and photon emitters at 4 millirems effective dose equivalent per year (mrem ede/yr) to protect against cancer risk. Drinking water that meets the EPA standard is associated with little of the risk and is considered safe for beta and photon emitters.

* * * * *

7. A new section § 141.44 is added to subpart E to read as follows:

§ 141.44 Special monitoring for radionuclides.

(a) Each community and non-transient, non-community water system shall take one sample at each sampling point for lead-210 and report the results to the State. Monitoring must be completed by December 1996.

(b) Groundwater systems shall take a minimum of one sample at every entry point to the distribution system which is representative of each well after treatment (hereafter called a sampling point). Each sample must be taken at the same sampling point unless conditions

make another sampling point more representative of each source or treatment plant.

(c) Surface water systems.

Note: For purposes of this paragraph, surface water systems include systems with a combination of surface and ground sources.

shall take a minimum of one sample at points in the distribution system that are representative of each source or at each entry point to the distribution system after treatment (hereafter called a sampling point). Each sample must be taken at the same sampling point unless conditions make another sampling point more representative of each source or treatment plant.

(d) If the system draws water from more than one source and the sources are combined before distribution, the system must sample at an entry point to the distribution system during periods of normal operating conditions (i.e., when water representative of all sources is being used).

(e) The State may require a confirmation sample for positive or negative results.

(f) Instead of performing the monitoring required by this section, a community water system or non-transient non-community water system serving fewer than 150 service connections may send a letter to the State stating that the system is available for sampling. This letter must be sent to the State by January 1, 1996. The system shall not send such samples to the State, unless requested to do so by the State.

8. A new § 141.53 is added to subpart F to read as follows:

§ 141.53 Maximum contaminant level goals for Radionuclides.

MCLGs for the radionuclides are as follows:

Contaminant	MCLG
Radon 222	Zero.
Radium-226	Zero.
Radium-228	Zero.
Uranium	Zero.
Gross alpha emitters	Zero.
Beta and photon emitters	Zero.

9. A new section 141.64 is added to subpart G to read as follows:

§ 141.64 Maximum contaminant levels for radionuclides.

(a) The following maximum contaminant levels for Radionuclides apply to community and non-transient, non-community water systems. The effective date for these MCLs is [insert date 18 months after publication of the final rule in the Federal Register].

Contaminant	MCL
(1) Radon-222	300 pCi/l.
(2) Radium-226	20 pCi/l.
(3) Radium-228	20 pCi/l.
(4) Uranium	20 µg/l. ¹
(5) Adjusted gross alpha	15 pCi/l.
(6) Beta particle and photon emitters.	4 mrem ede/yr. ²

¹ NOTE: 20 µg/l uranium is approximately equal to 30 pCi/l, using an activity-to-mass conversion of 1.3 pCi/µg. The activity-to-mass ratio can vary depending on the relative amounts of uranium-234, -235 and -238 that are present in a sample. The MCL applies to the total mass of uranium in the sample.

² NOTE: The unit mrem ede/yr refers to the dose committed over a period of 50 years to reference man (ICRP 1975) from an annual intake at the rate of 2 liters of drinking water per day.

(b) The Administrator, pursuant to section 1412 of the Act, hereby identifies as indicated in the table below the best technology, treatment technique, or other means available for achieving compliance with the maximum contaminant level for Radionuclides identified in paragraph (a) of this section:

BAT FOR RADIONUCLIDES LISTED IN SECTION 141.64

Contaminant	BAT
Radon 222	Aeration: Packed tower, spray, slat tray and other forms.
Radium 226	Ion exchange, Reverse osmosis, Lime softening.
Radium 228	Ion exchange, Reverse osmosis, Lime softening.
Uranium (N)	Ion exchange, reverse osmosis, Lime softening, coagulation/filtration.
Alpha particle emitters.	Reverse osmosis.
Beta particle and photon emitters.	Mixed bed ion exchange, Reverse osmosis.

PART 142—NATIONAL PRIMARY DRINKING WATER REGULATIONS IMPLEMENTATIONS

1. The authority citation for part 142 continues to read as follows:

Authority: 42 U.S.C. 300g, 300g-1, 300g-2, 300g-3, 300g-4, 300g-5, 300g-6, 300j-4, and 300j-9.

2. Section 142.14 is amended by adding paragraphs (d)(12) and (d)(13).

§ 142.14 Records kept by States.

* * * * *

(d) * * *

(12) Records of any determination of a system's vulnerability to contamination from photon and beta emitters due to their proximity to an emitting source or use of source water influenced by a source of radiation. The records shall also include the basis for such determination.

(13) Records of all current monitoring requirements and the most recent monitoring frequency decision pertaining to each contaminant, including the monitoring results and other data supporting the decision, the State's findings based on the supporting data and any additional bases for such decision; records shall be kept in perpetuity or until a more recent monitoring frequency decision has been issued.

* * * * *

3. In § 142.15 is amended by adding a new paragraph (c)(5) to read as follows:

§ 142.15 Reports by States.

* * * * *

(c) * * *

(5) The results of monitoring for the unregulated contaminants in § 141.44 shall be reported within one quarter after the December 1996 completion date for monitoring lead-210.

* * * * *

4. Section 142.16 is amended by adding a new paragraph (f) to read as follows:

§ 142.16 Special primacy requirements.

* * * * *

(f) An application for approval of a State program revision for Radionuclides which adopts the requirements specified in §§ 141.25, 141.32, 141.44, and 141.64 must contain the following (in addition to the general primacy requirements enumerated elsewhere in this part, including the requirement that state regulations be at least as stringent as the federal requirements):

(1) If a State chooses to issue waivers from the monitoring requirements in §§ 141.25 and 141.44, the State shall describe the procedures and criteria which it will use to review waiver applications and issue waiver determinations.

(i) The procedures for each contaminant or class of contaminants shall include a description of:

(A) The waiver application requirements;

(B) The State review process for reviewing waiver applications;

(ii) The State decision criteria, including the factors that will be considered in deciding to grant or deny waivers. The decision criteria must include the factors specified in §§ 141.25(b)(4) and 141.25(c)(3).

(2) A State shall determine what systems are vulnerable to beta and photon emitting sources. States shall specify the procedures they will use to decide which systems are vulnerable. Vulnerability of each public water

system shall be determined by the State based upon an assessment of the following factors:

(i) Proximity of water system to a potentially discharging source, such as a nuclear power facility, or where there is a commercial or industrial use, disposal, or storage of the materials;

(ii) Previous monitoring results; and

(iii) Use of water influenced by a nuclear power facility or other potential discharger.

5. A new § 142.65 is added to subpart G to read as follows:

§ 142.65 Variances and Exemptions from the maximum contaminant levels for the radionuclide contaminants listed in § 141.64.

(a) The Administrator, pursuant to section 1415(a)(1)(A) of the Act, hereby identifies the following as the best technology, treatment techniques, or other means available for achieving compliance with the maximum contaminant levels for the radionuclides listed in § 141.64, for the purpose of issuing variances and exemptions.

BAT FOR RADIONUCLIDES LISTED IN § 141.64

Contaminant	BAT
Radon 222.....	1.
Radium 226.....	2,3,4.
Radium 228.....	2,3,4.
Uranium (N).....	2,3,4,5.
Gross alpha particle emitters.....	3.
Gross beta particle and photon emitters.....	3,6.

Key to BATs in table:
 1=Aeration: Packed Tower, spray, slat tray and other forms.
 2=Ion exchange.
 3=Reverse osmosis.
 4=Lime softening; except for systems serving 500 or fewer connections.
 5=Coagulation/filtration; except for systems serving 500 or fewer connections.
 6=Mixed bed ion exchange.

(b) A State shall require community water systems and non-transient, non-community water systems to install and/or use any treatment method identified in § 141.64 as a condition for granting a variance except as provided in paragraph (c) of this section. If, after the system's installation of the treatment method, the system cannot meet the MCL, that system shall be eligible for a variance under the provisions of section 1415(a)(1)(A) of the Act.

(c) If a system can demonstrate through comprehensive engineering assessment, which may include pilot

plant studies that the treatment methods identified in § 141.64 would only achieve a de minimis reduction in contaminants, the State may issue a schedule of compliance that requires the system being granted the variance to examine other treatment methods as a condition of obtaining the variance.

(d) If the State determines that a treatment method identified in paragraph (c) of this section is technically feasible, the Administrator or primary State may require the system to install and/or use that treatment method in connection with a compliance schedule issued under the provisions of section 1415(a)(1)(A) of the Act. The State's determination shall be based upon studies by the system and other relevant information.

(e) The State may require a public water system to use bottled water (except for radon) or other means as a condition of granting a variance or an exemption from the requirements of § 141.64, to avoid an unreasonable risk to health. Granular activated carbon point-of-use devices cannot be used as a means of being granted a variance or an exemption for radon.

(f) Public water systems that use bottled water as a condition for receiving a variance or an exemption from the requirements of § 141.64 must meet the following requirements. Bottled water cannot be used as a means of being granted a variance or an exemption for radon.

(1) The Administrator or primacy State must require and approve a monitoring program for bottled water. The public water system must develop and put in place a monitoring program that provides reasonable assurances that the bottled water meets all MCLs. The public water system must monitor a representative sample of the bottled water for all contaminants under regulated § 141.64 the first quarter that it supplies that bottled water to the public, and annually thereafter. Results of the monitoring program shall be provided to the State annually; or

(2) The public water system must receive a certification from the bottled water company that the bottled water supplied has been taken from an "approved source" as defined in 21 CFR 129.3(a); the bottled water company has conducted monitoring in accordance with 21 CFR 129.80(g) (1) through (3); and the bottled water does not exceed any MCLs or quality limits as set out in

21 CFR 103.35, 110, and 129. The public water system shall provide the certification to the State the first quarter after it supplies bottled water and annually thereafter; and

(3) The public water system is fully responsible for the provision of sufficient quantities of bottled water to every person supplied by the public water system, via door-to-door bottled water delivery.

(g) Public water systems that use point-of-use devices as a condition for obtaining a variance or an exemption from NPDWRs for Radionuclides (except radon, as POU treatment is not allowed for variances to the radon MCL) must meet the following requirements:

(1) It is the responsibility of the public water system to operate and maintain the point-of-use device.

(2) The public water system must develop a monitoring plan and obtain State approval for the plan before point-of-use devices are installed for compliance. This monitoring plan must provide health protection equivalent to a monitoring plan for central water treatment.

(3) Effective technology must be properly applied under a plan approved by the State.

(4) The State must require adequate certification of performance, field testing, and if not included in the certification process, a rigorous engineering design review of the point-of-use devices.

(5) The design and application of the point-of-use devices must consider the tendency for an increase in heterotrophic bacteria concentrations in water treated with activated carbon. It may be necessary to use frequent backwashing, post-contactor disinfection, and Heterotrophic Plate Count monitoring to ensure that the microbiological safety of the water is not compromised.

(6) All consumers shall be protected. Every building connected to the system must have a point-of-use device installed, maintained, and adequately monitored. The State must be assured that every building is subject to treatment and monitoring and that the rights and responsibilities of the public water system customer convey with title upon sale of property.

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